

New Physics in $b \rightarrow s$ Processes

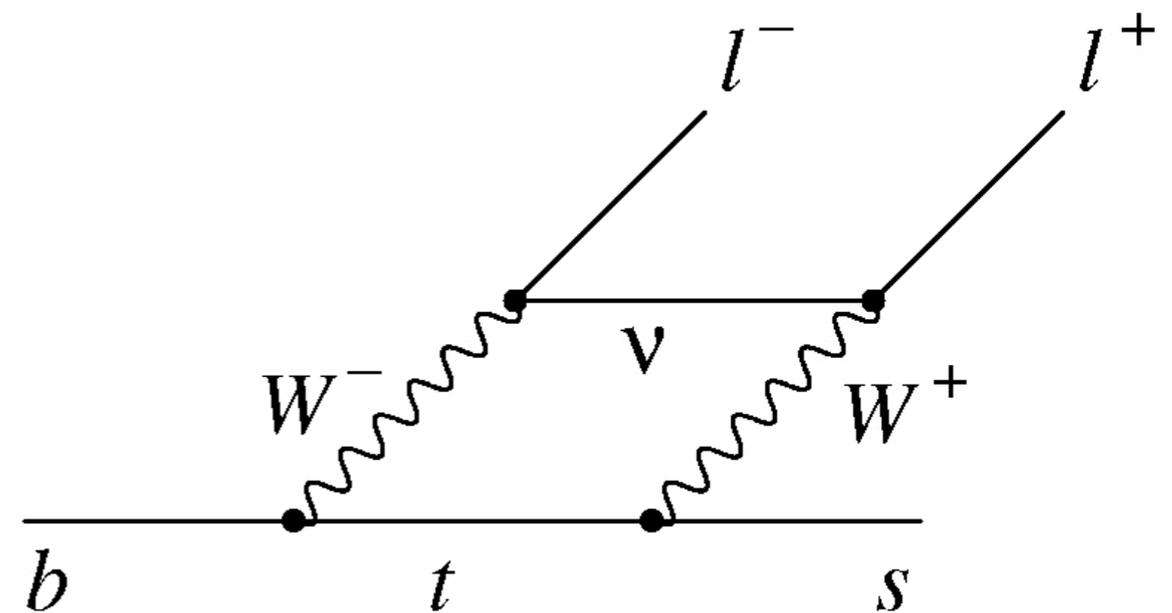
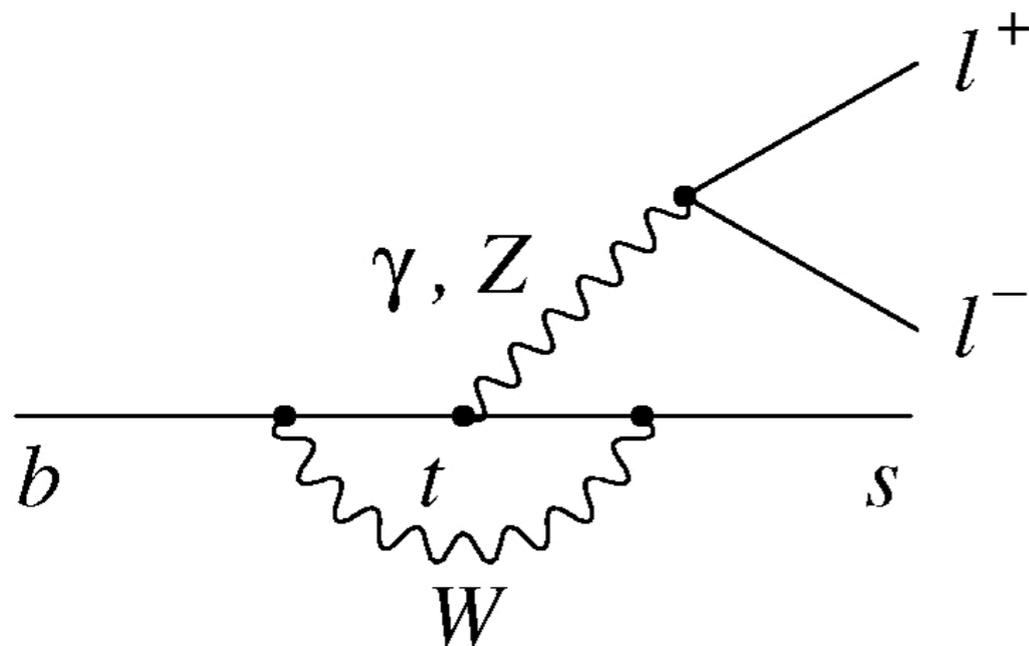
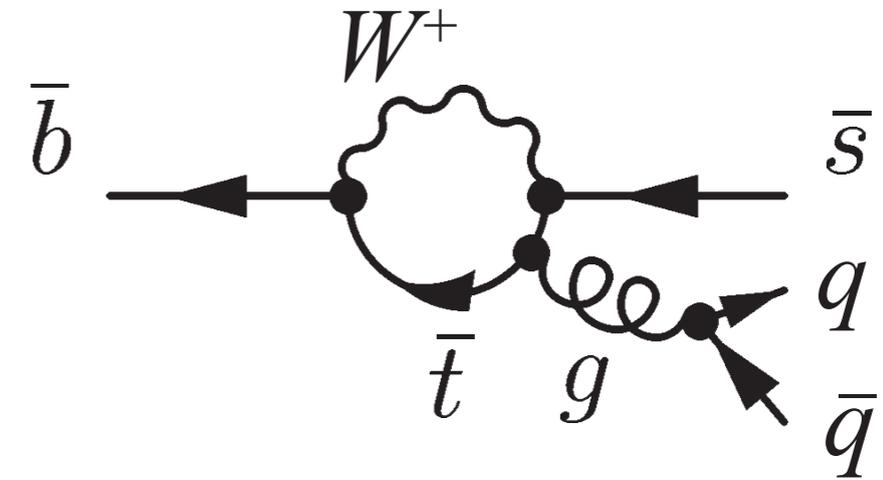
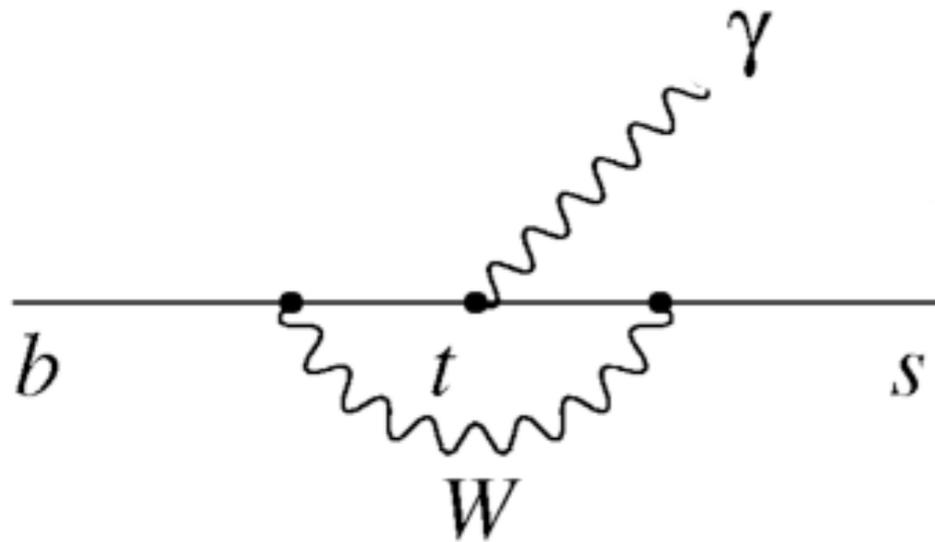
*Leo Piilonen, Virginia Tech
on behalf of the Belle and BaBar Collaborations*



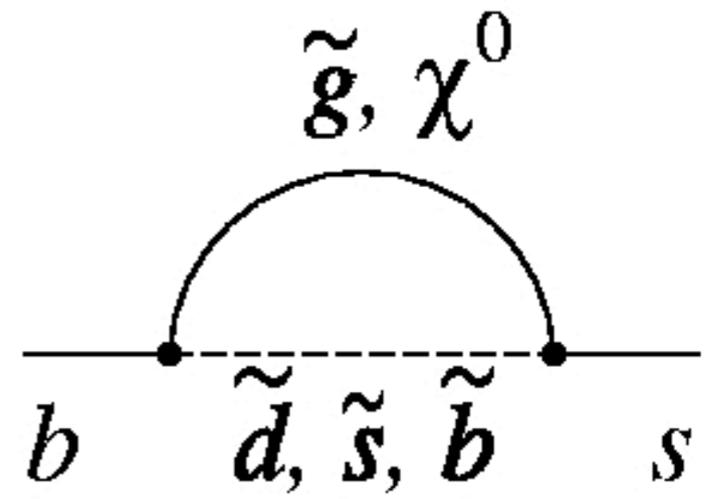
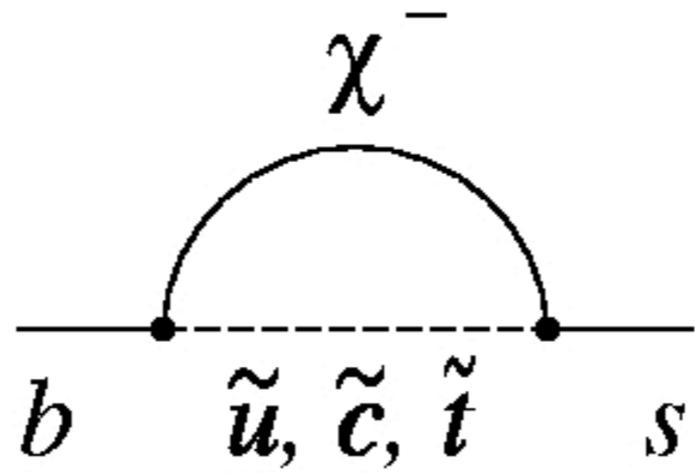
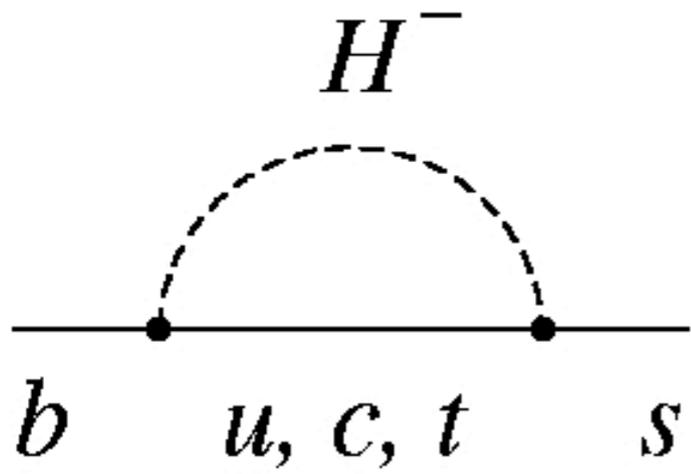
Brookhaven Forum 2008



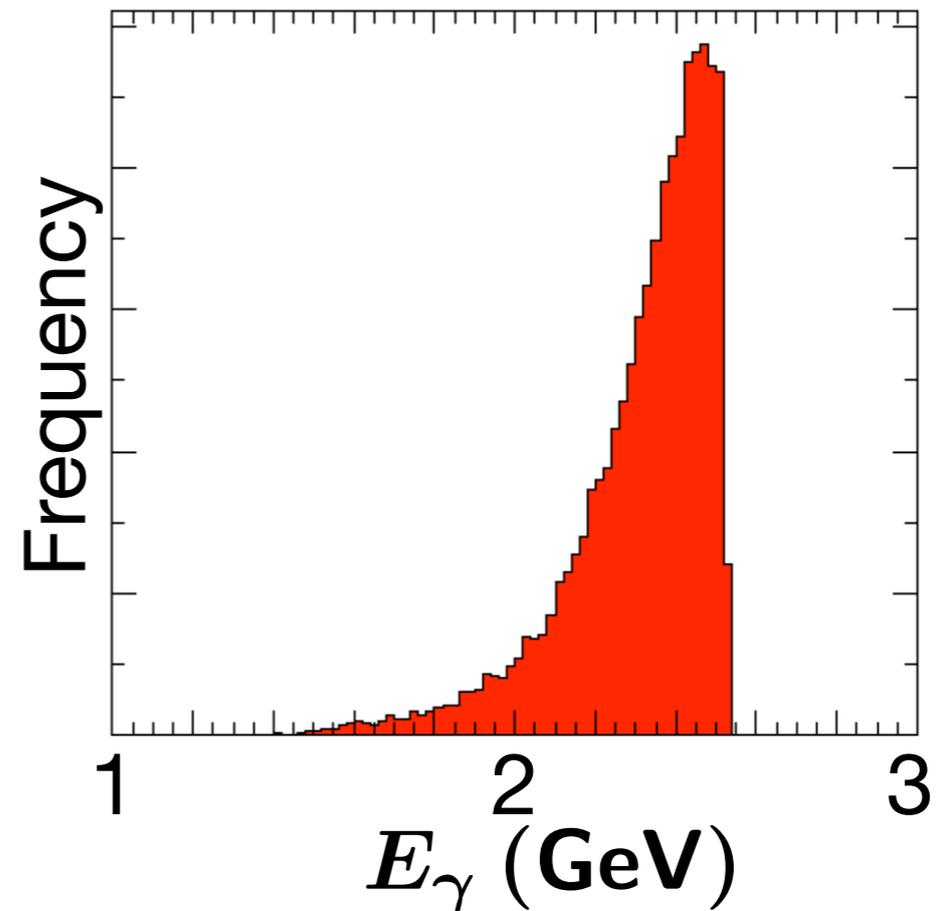
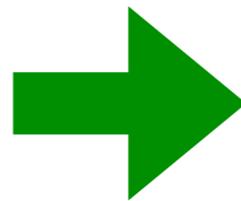
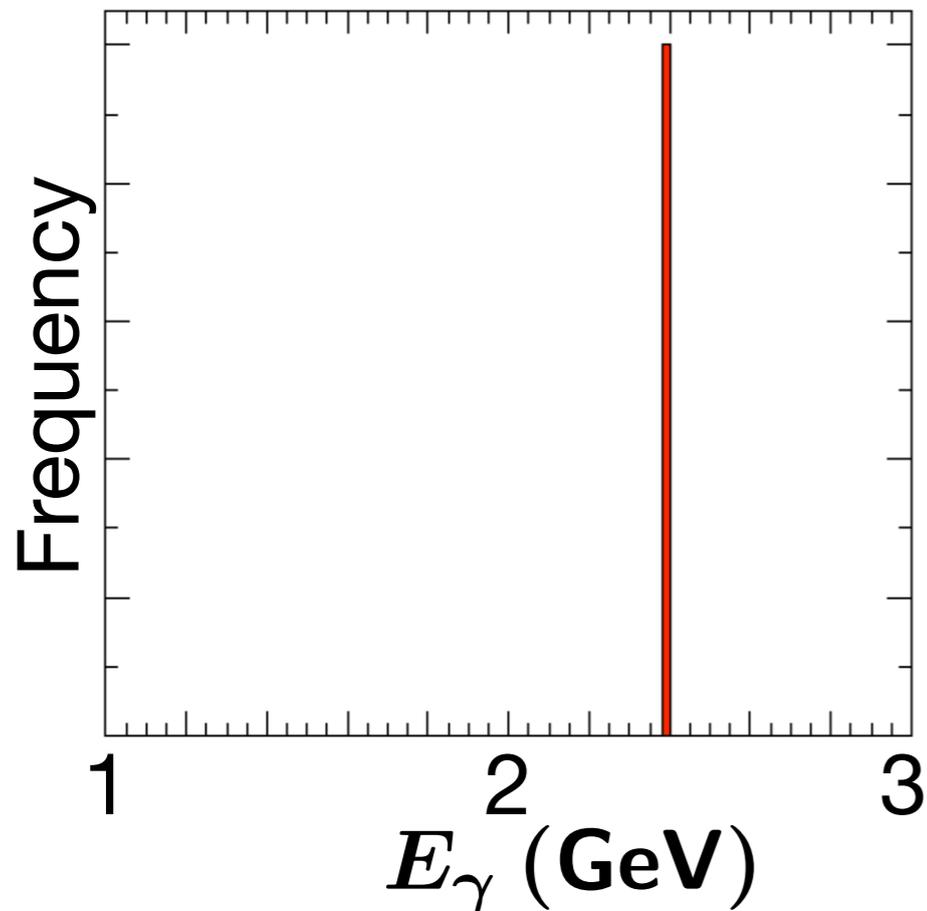
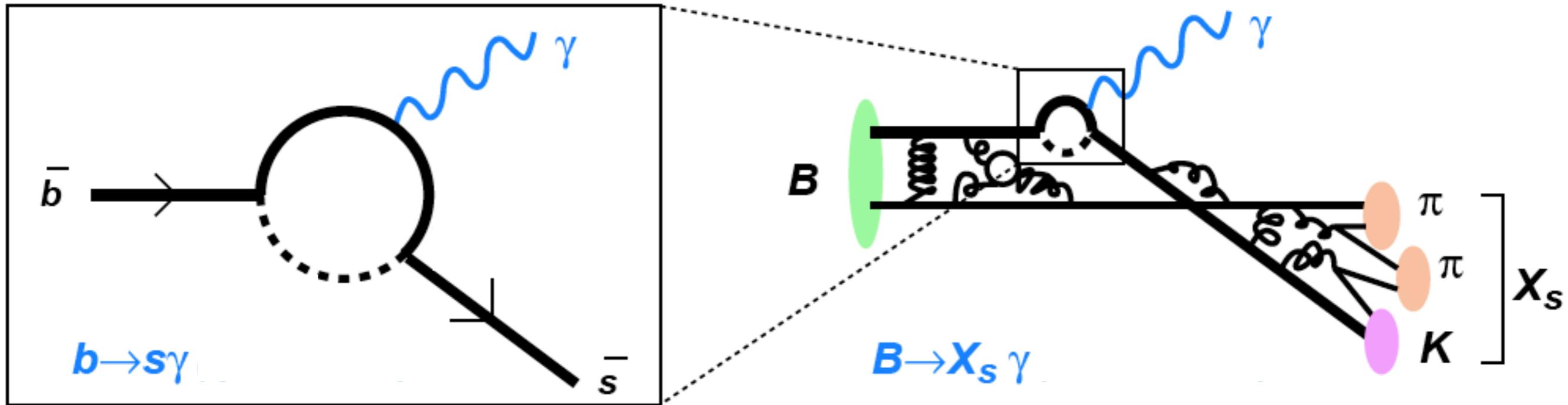
Flavor-changing neutral current transitions are forbidden at the tree level in the standard model



... so new physics can enter at the same order as the standard model contributions



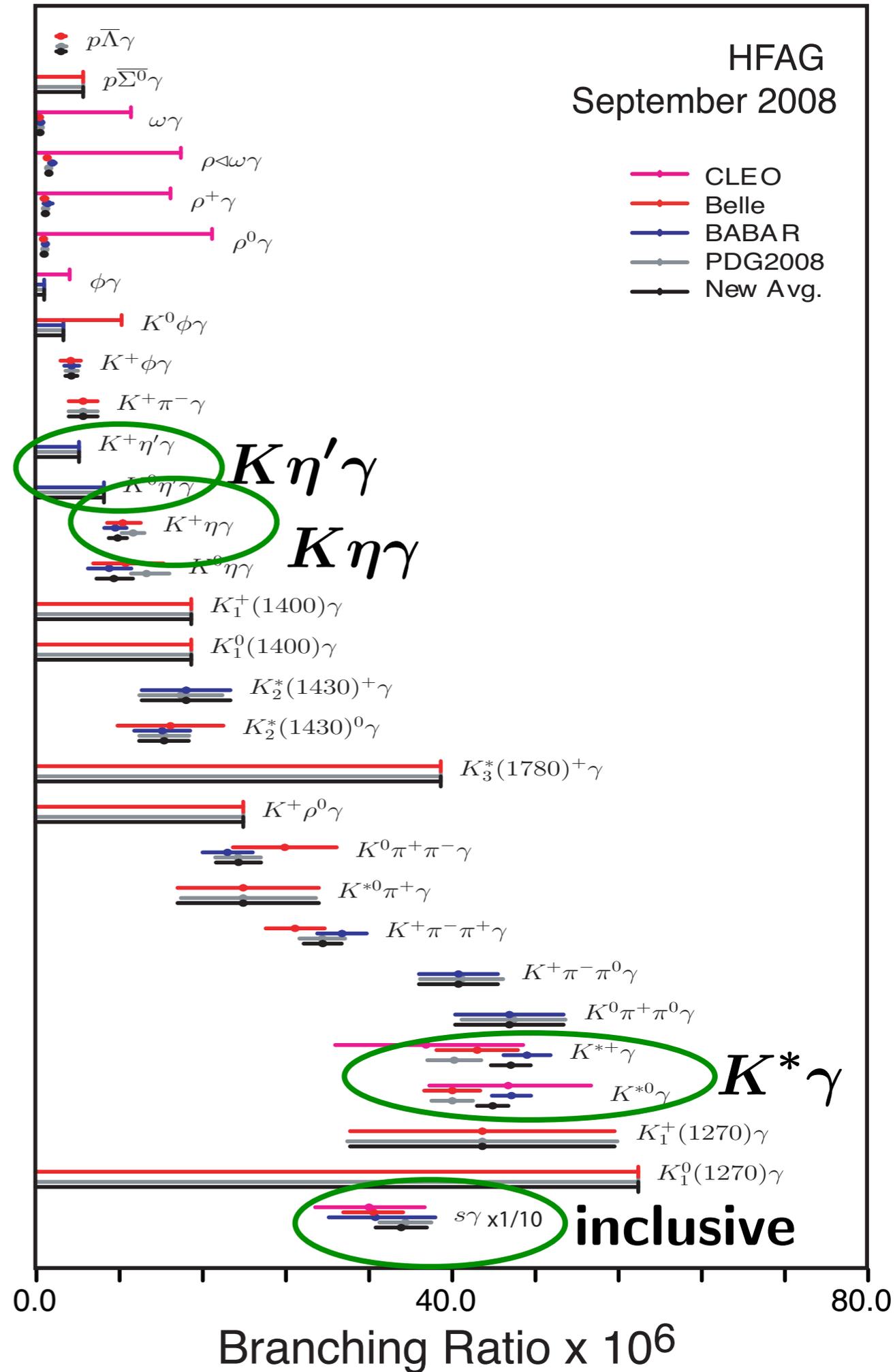
Reliability of calculating hadronic effects limits the sensitivity to new physics (cf $\mu \rightarrow e\gamma$)



b → *sγ*

Many exclusive $b \rightarrow s\gamma$ modes have been observed by CLEO, Belle, and BaBar.

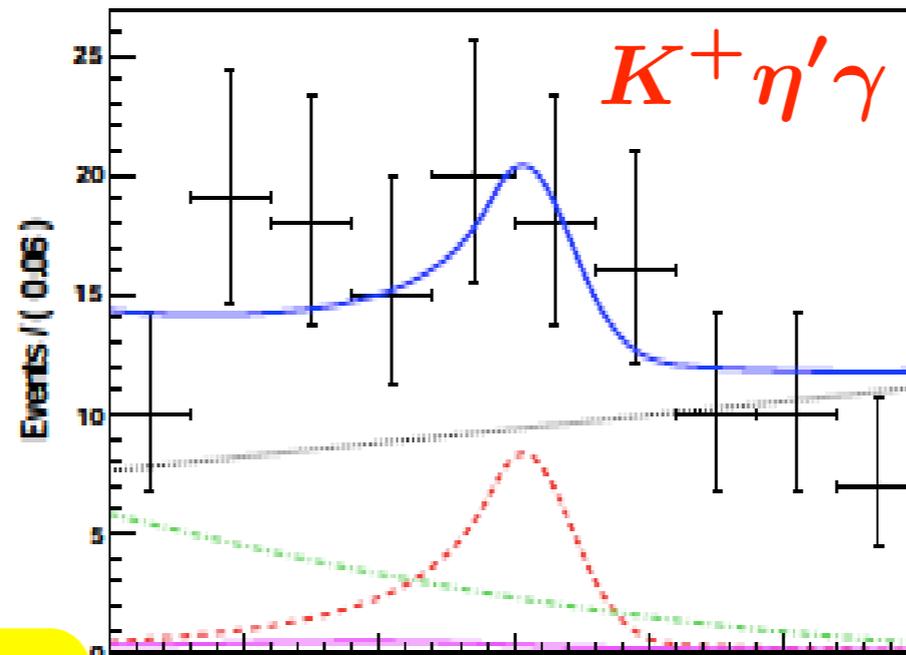
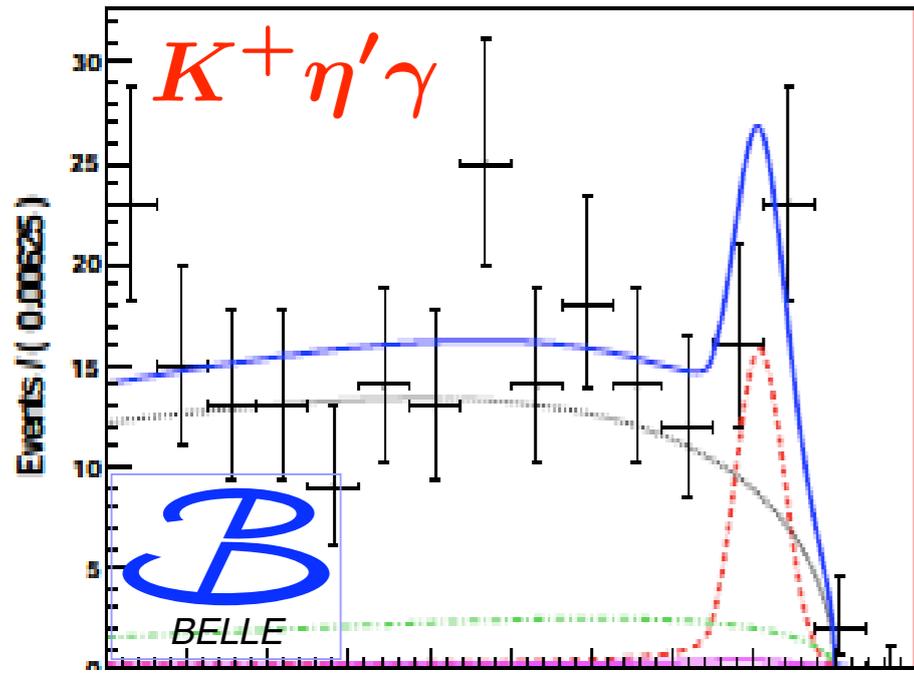
Hadronic form factor uncertainties make predictions of exclusive branching ratios imprecise.



Branching ratios for $B \rightarrow K\eta'\gamma$:

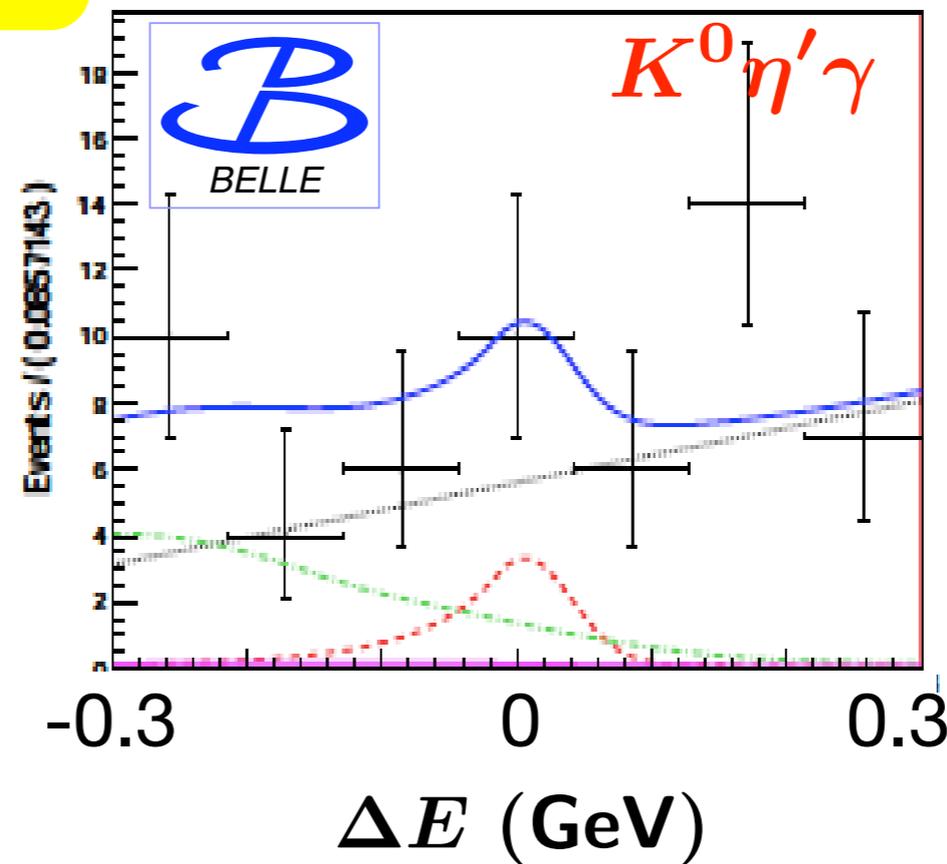
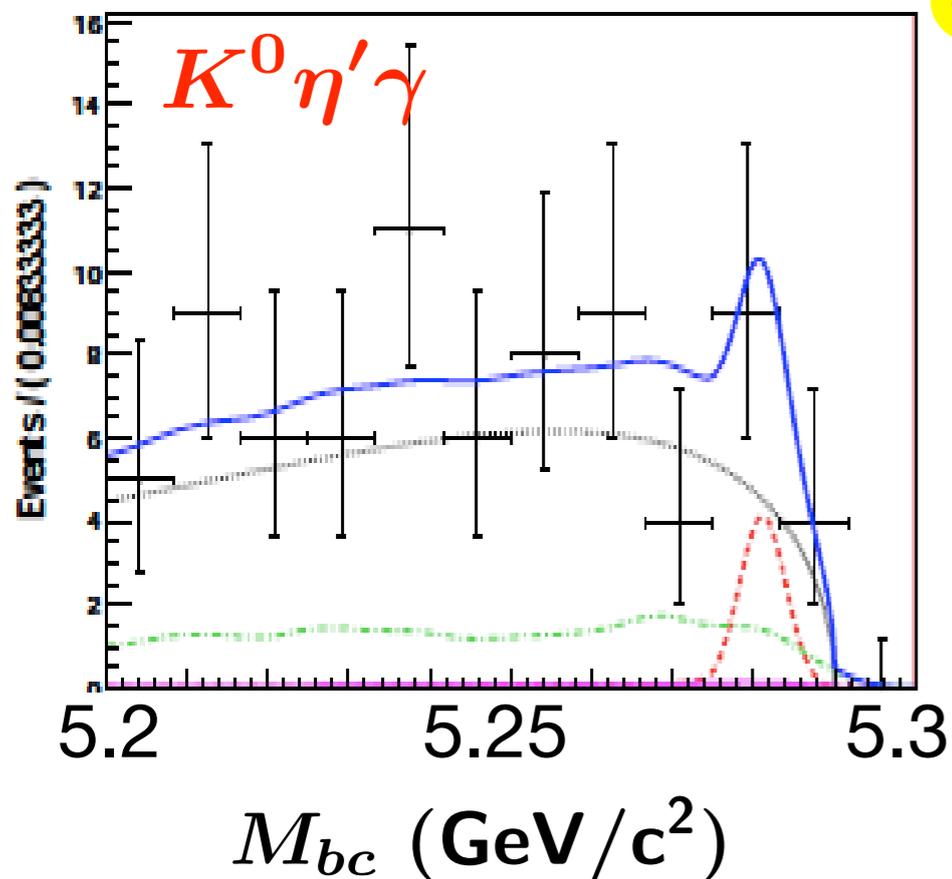
657M $B\bar{B}$

arXiv:0810.0804



$S = 3.3\sigma$
First evidence!

New



$S = 1.3\sigma$

Branching ratios for $B \rightarrow K \eta' \gamma$:



657M $B\bar{B}$

arXiv:0810.0804 (2008)



232M $B\bar{B}$

PRD 74, 031102 (2006)

| Mode | $\mathcal{B}(\times 10^{-6})$ | $\mathcal{B}(\times 10^{-6})$ |
|--------------------|---------------------------------------|-------------------------------|
| $K^0 \eta' \gamma$ | $2.4 \pm_{0.9}^{2.4} \pm_{0.5}^{0.4}$ | |
| | < 6.3 | < 6.6 |
| $K^+ \eta' \gamma$ | $3.2 \pm_{1.1}^{1.2} \pm 0.3$ | < 4.2 |

90% confidence level upper limits

... again, hard to predict these values precisely.

Possibly suppressed relative to $B \rightarrow K \eta \gamma$ due to destructive interference of two penguin diagrams.

Branching ratio for fully inclusive $B \rightarrow X_s \gamma$:

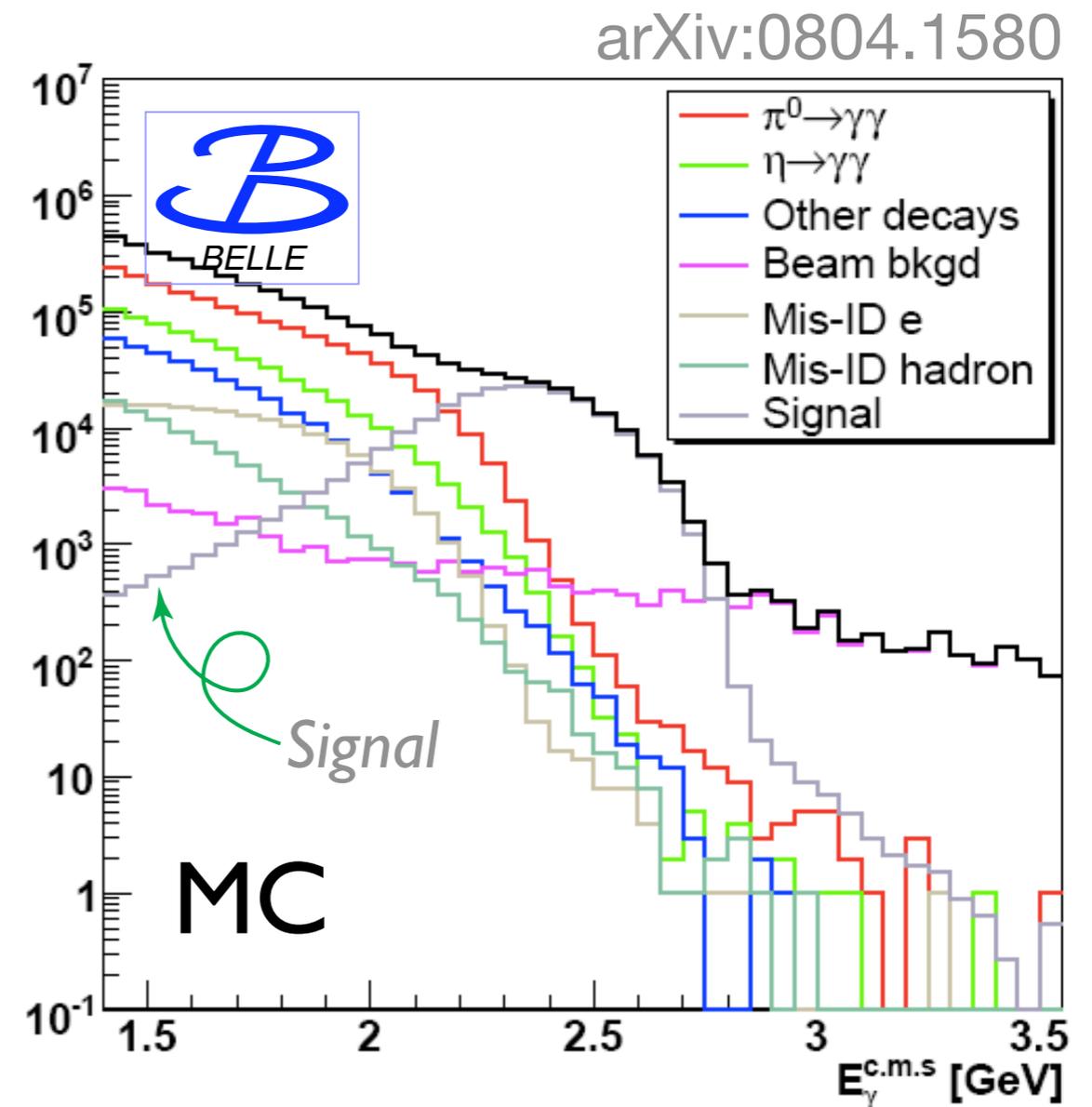
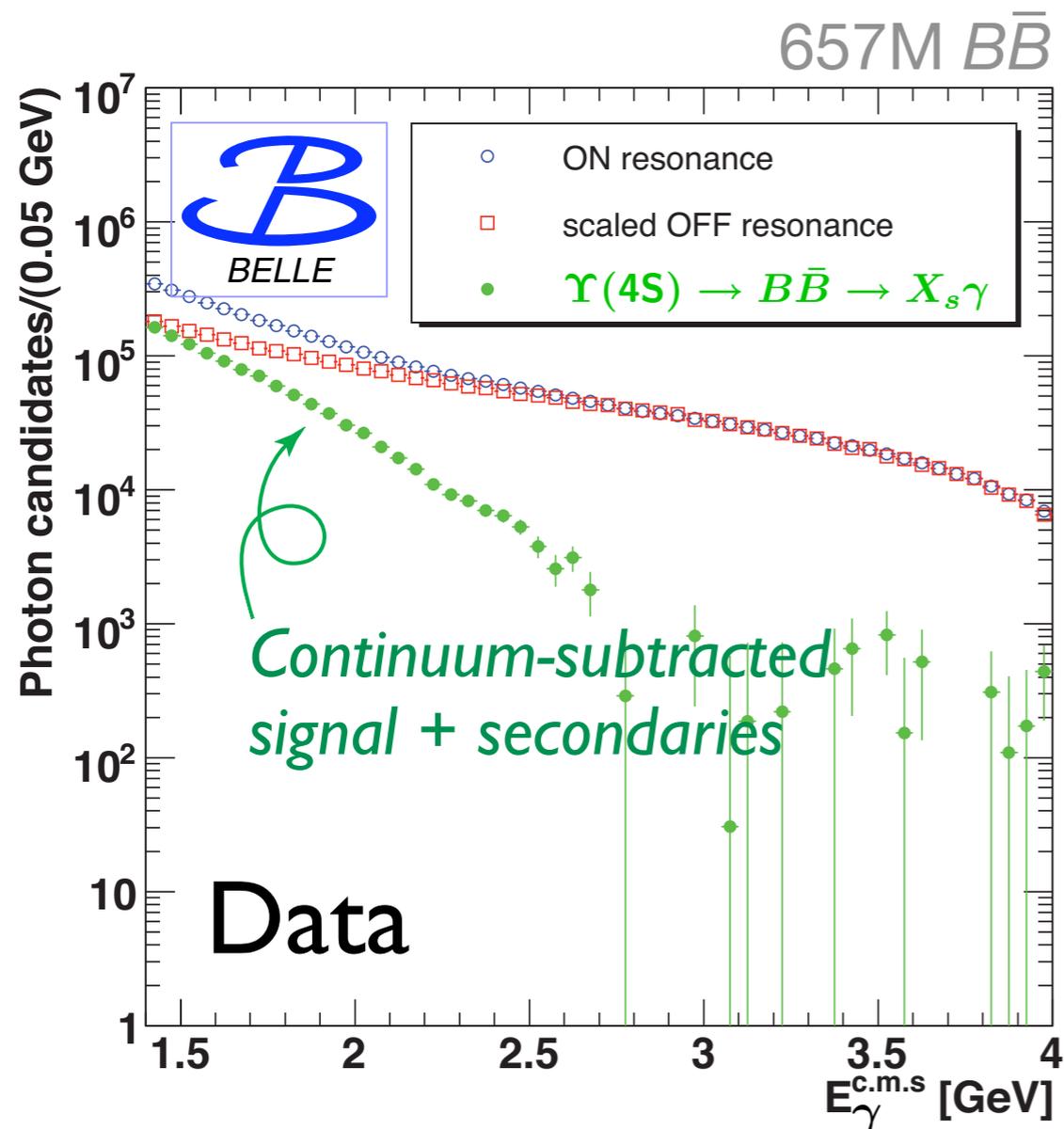
Fully-inclusive method:

Find isolated clusters in calorimeter with $E_\gamma^{\text{cm}} > 1.4 \text{ GeV}$

Veto photon from π^0 , η , and Bhabha

Suppress continuum background using topology; subtract remainder.

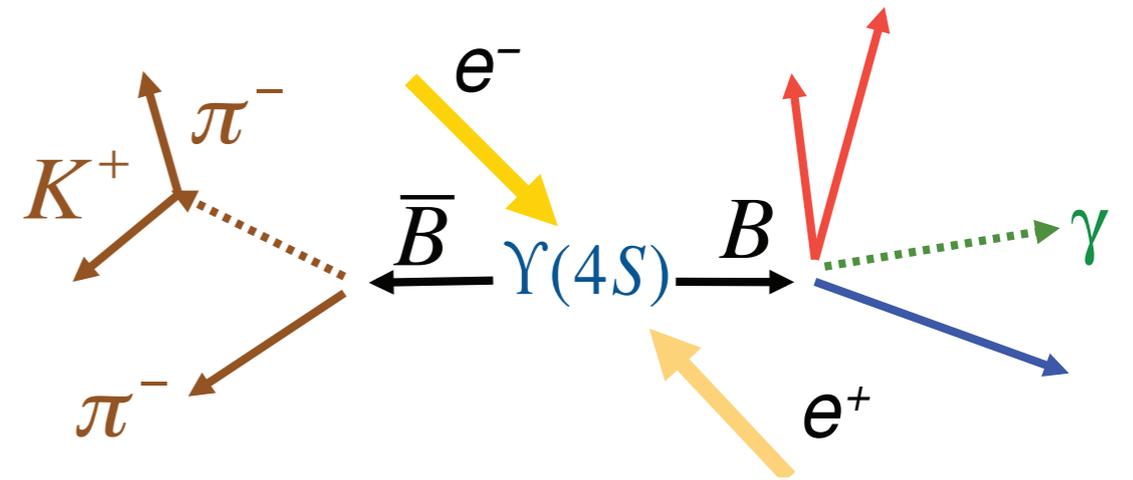
Subtract non-primary photons *using data to correct MC spectra*.



Branching ratio for fully inclusive $B \rightarrow X_s \gamma$:

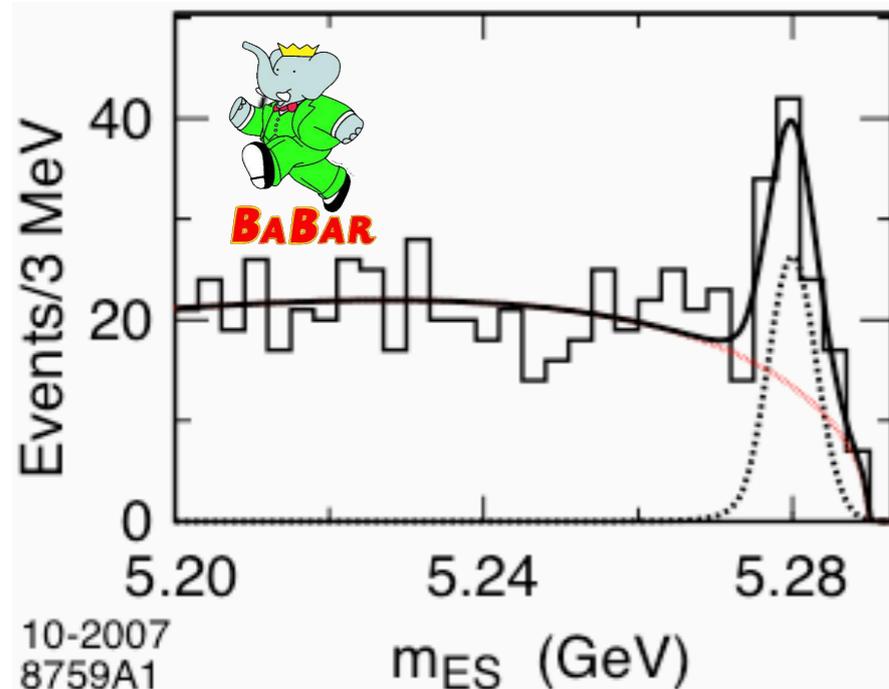
B-recoil method:

Reconstruct tag B to hadronic states.
Search for isolated photon in the rest of the event.
Subtract non-primary photons from B decays.



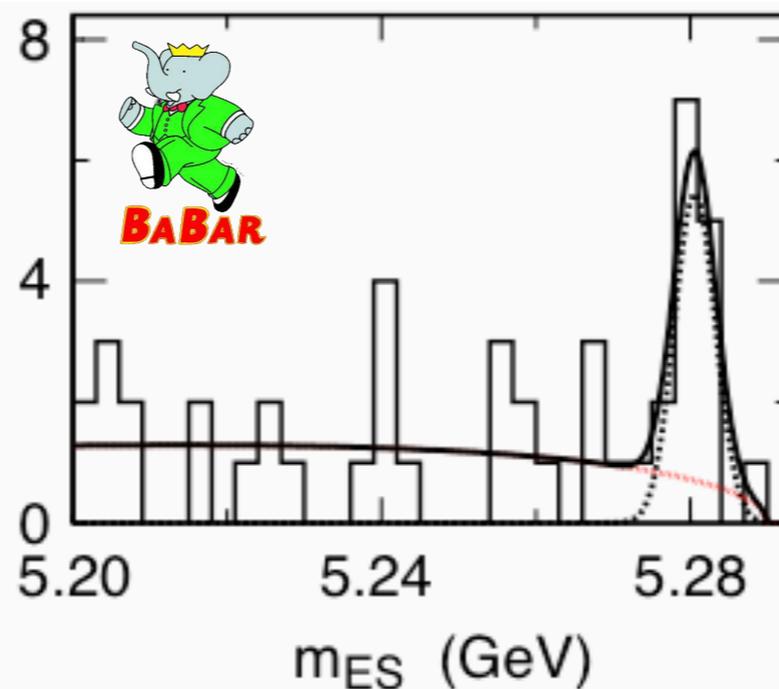
Provides B rest frame, B flavor/charge; suppresses continuum.

$1.6 < E_\gamma < 1.7 \text{ GeV}$

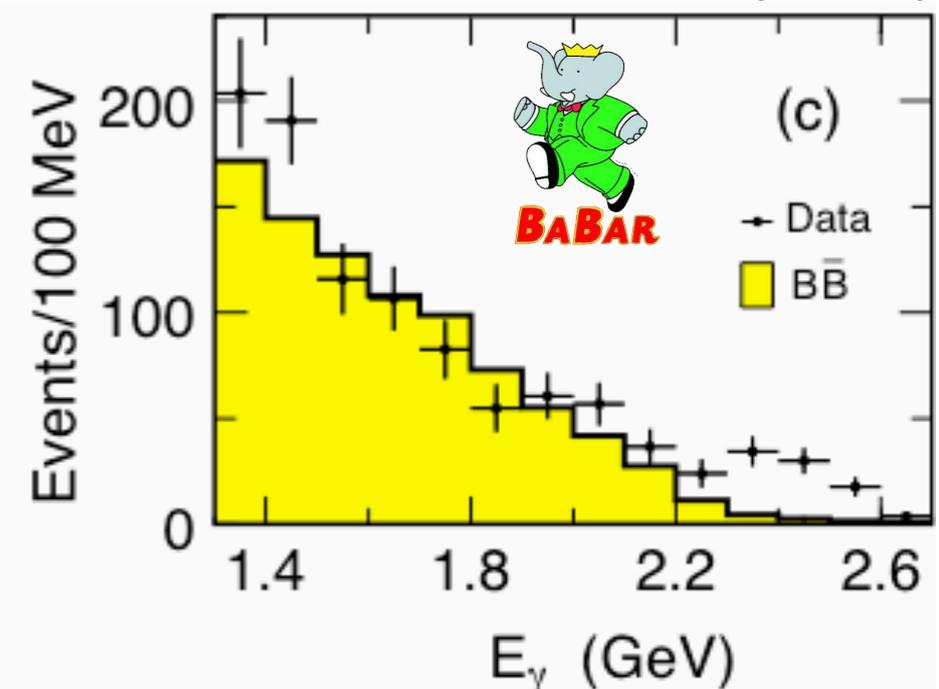


10-2007
8759A1

$2.3 < E_\gamma < 2.4 \text{ GeV}$



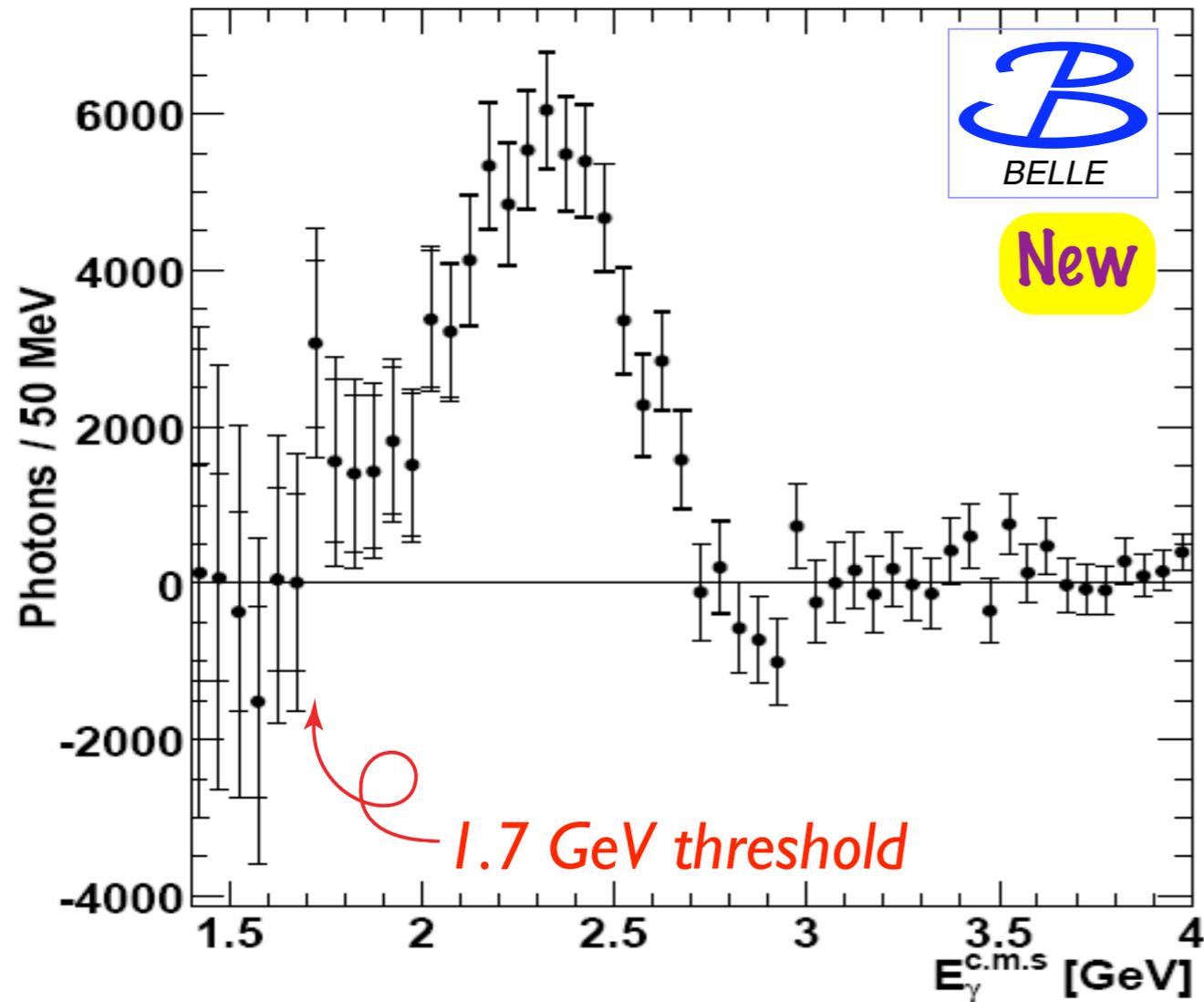
PRD 77,051103 (2008)



Branching ratio for fully inclusive $B \rightarrow X_s \gamma$:

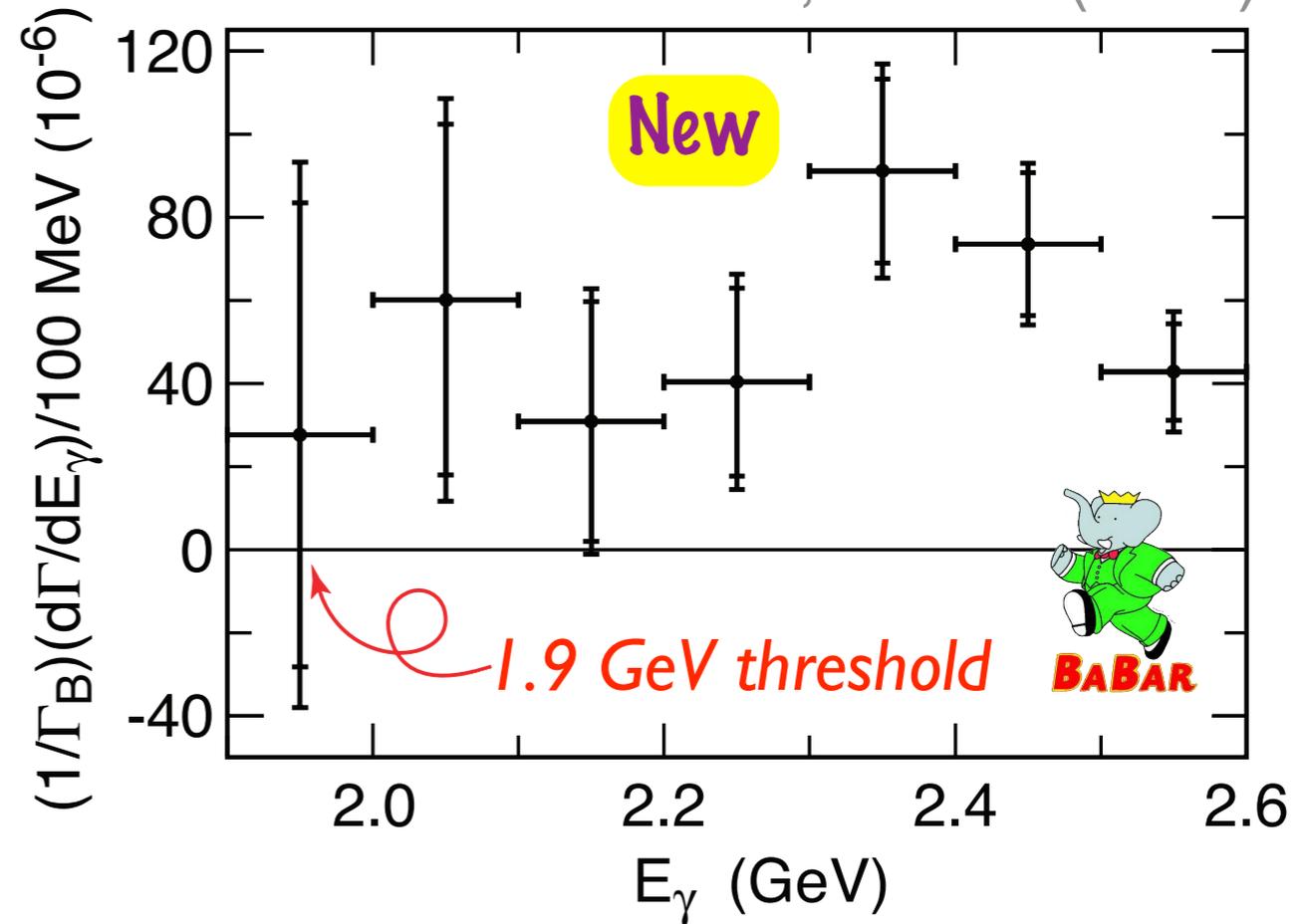
657M $B\bar{B}$

arXiv:0804.1580



Fully-inclusive method

0.68M $B\bar{B}$ PRD 77,051103 (2008)



B-recoil method

Branching ratio and moments for $B \rightarrow X_s \gamma$:



657M $B\bar{B}$

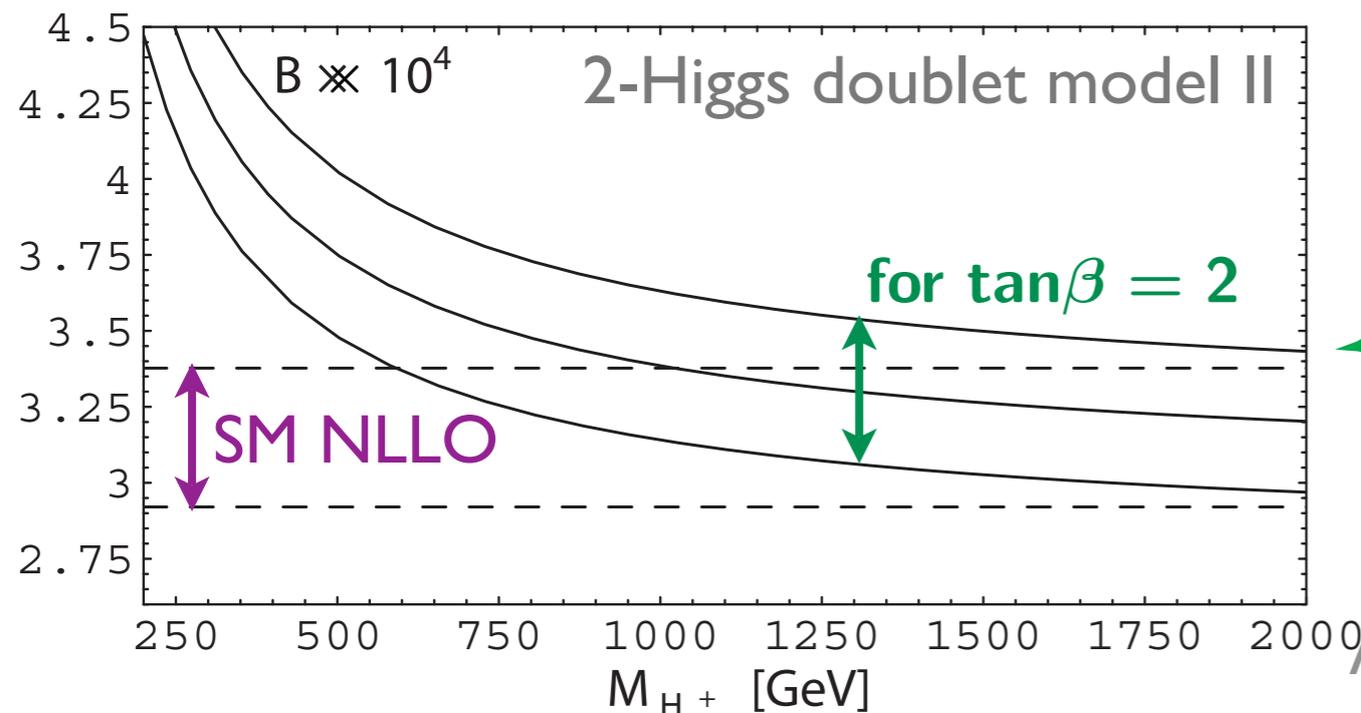
arXiv:0804.1580 (2008)



0.68M $B\bar{B}$

PRD 77,051103 (2008)

| | $E_\gamma > 1.7 \text{ GeV}$ | $E_\gamma > 1.9 \text{ GeV}$ |
|--|------------------------------|------------------------------|
| $\mathcal{B}(B \rightarrow X_s \gamma) (\times 10^{-4})$ | $3.31 \pm 0.19 \pm 0.37$ | $3.66 \pm 0.85 \pm 0.60$ |
| $\langle E_\gamma \rangle (\text{GeV})$ | $2.281 \pm 0.032 \pm 0.053$ | $2.289 \pm 0.058 \pm 0.027$ |
| $\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 (\text{GeV}^2)$ | $0.040 \pm 0.016 \pm 0.021$ | $0.033 \pm 0.012 \pm 0.006$ |



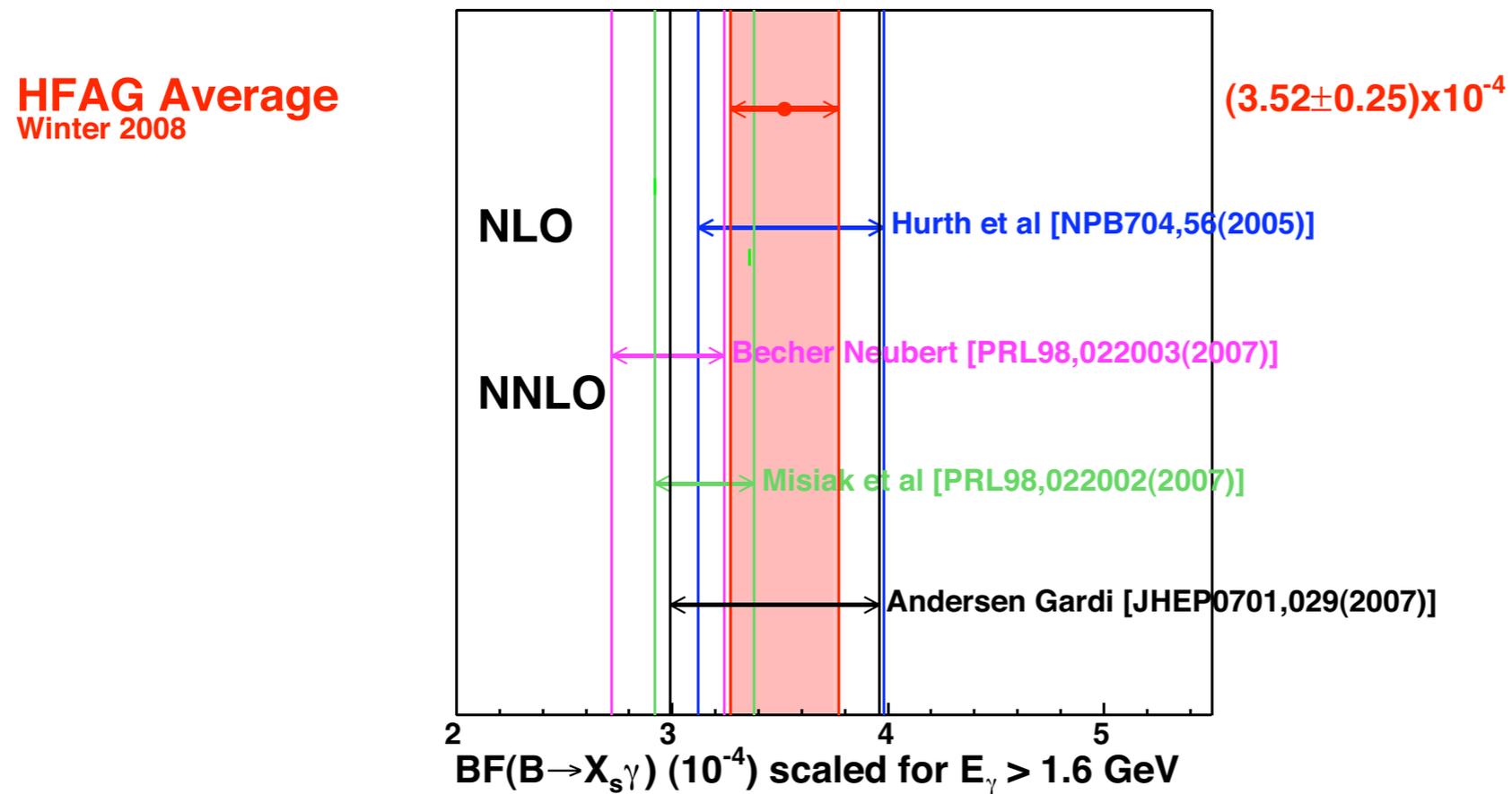
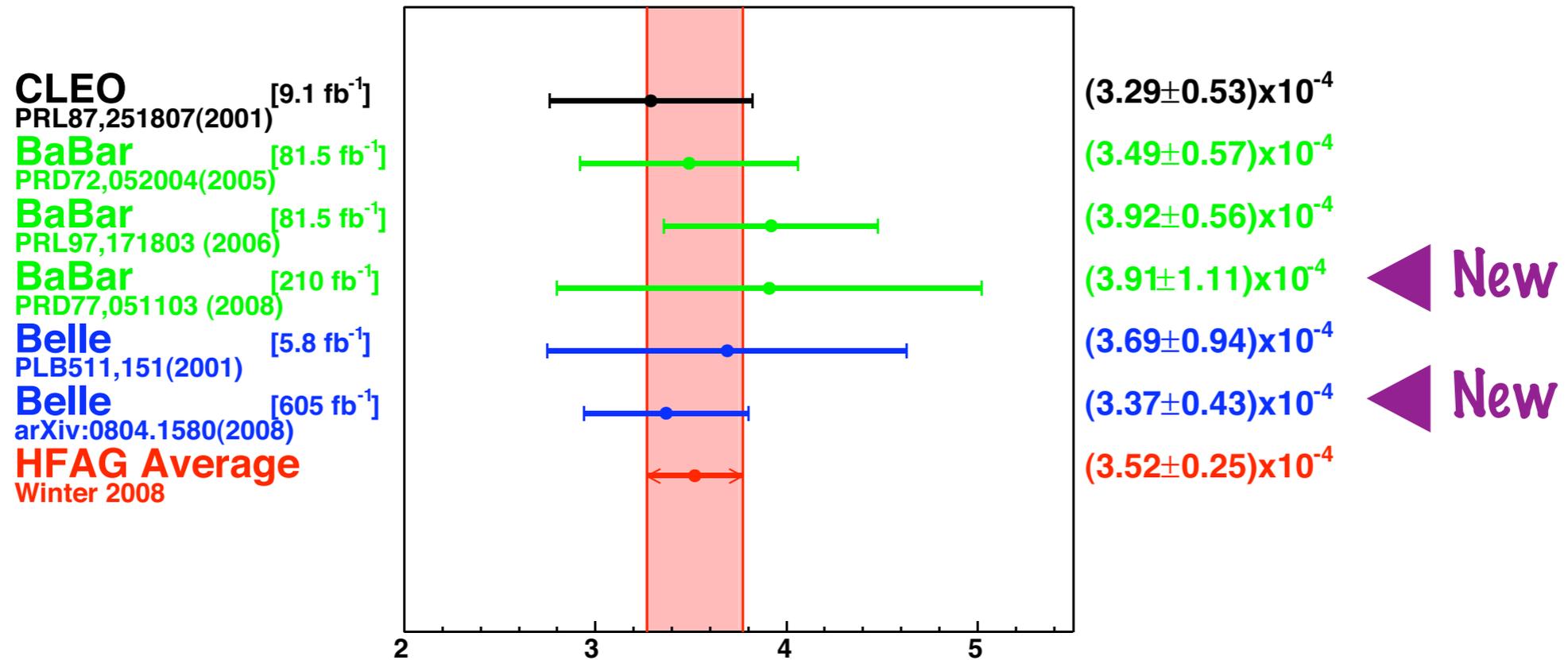
Consistent with SM expectations

Misiak et al: PRL 98, 022002 (2007)

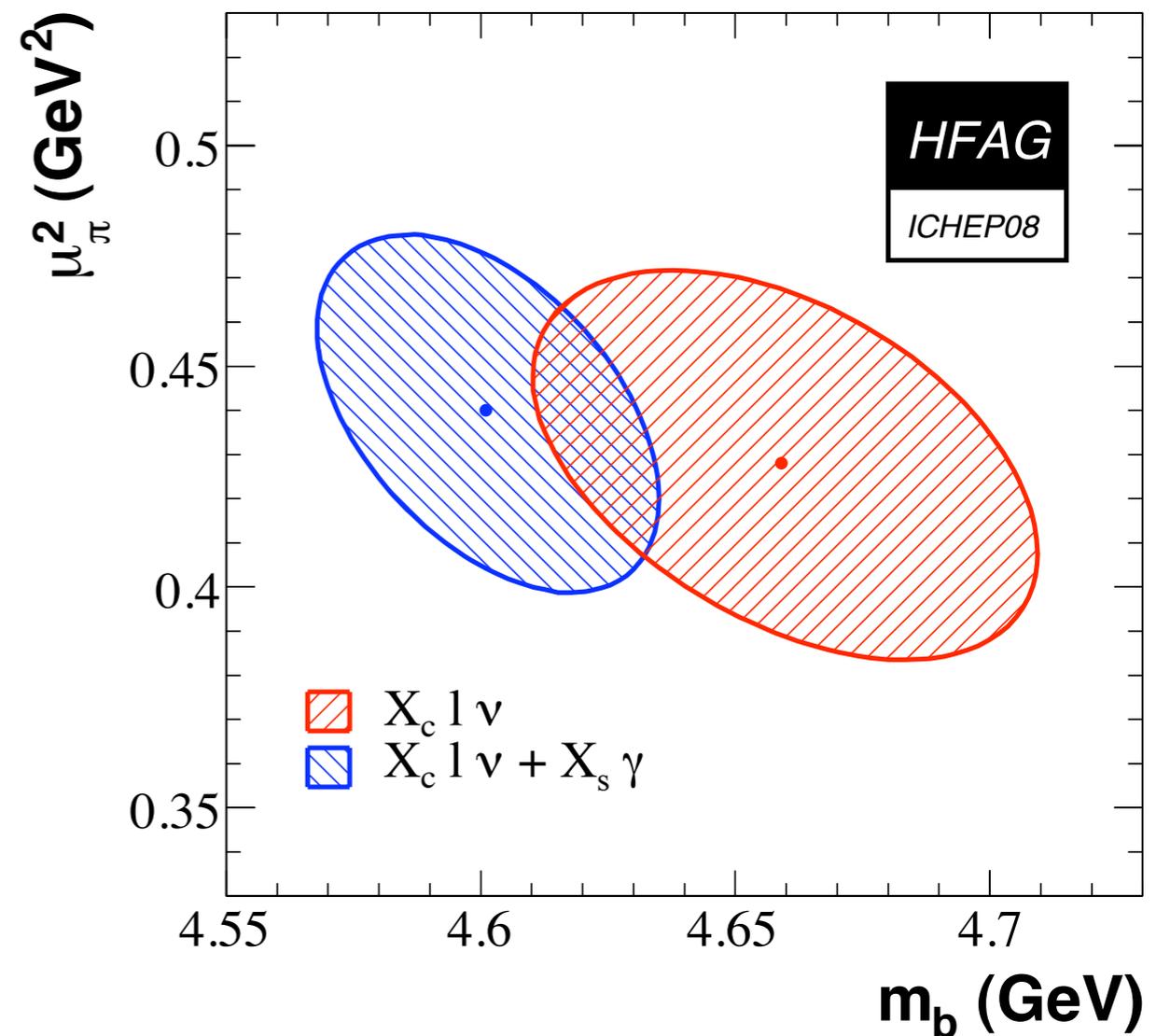
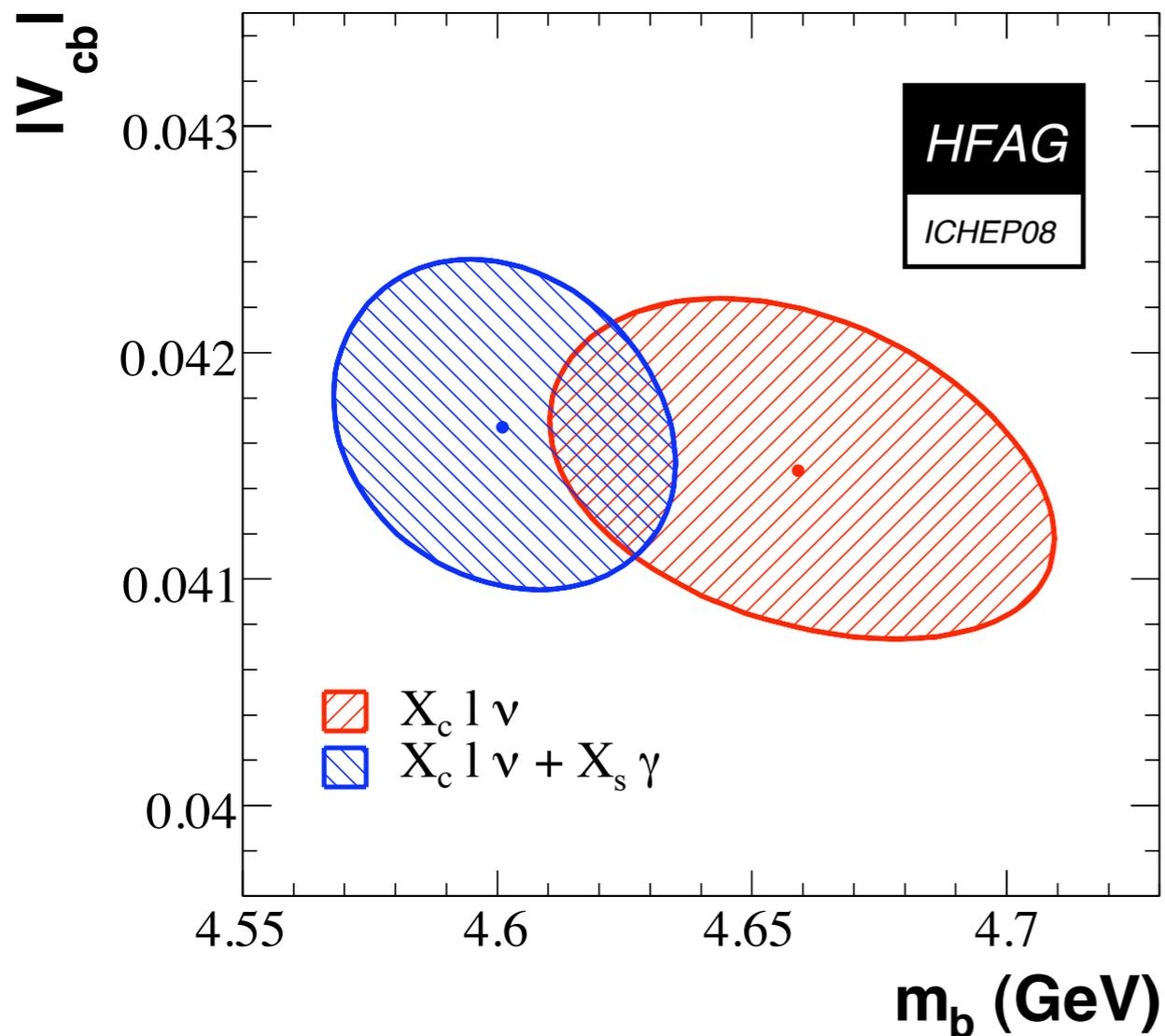
Becher & Neubert: PLB 637, 251 (2007)

Andersen & Gardi: JHEP 0701, 029 (2007)

Branching ratio for fully inclusive $B \rightarrow X_s \gamma$:



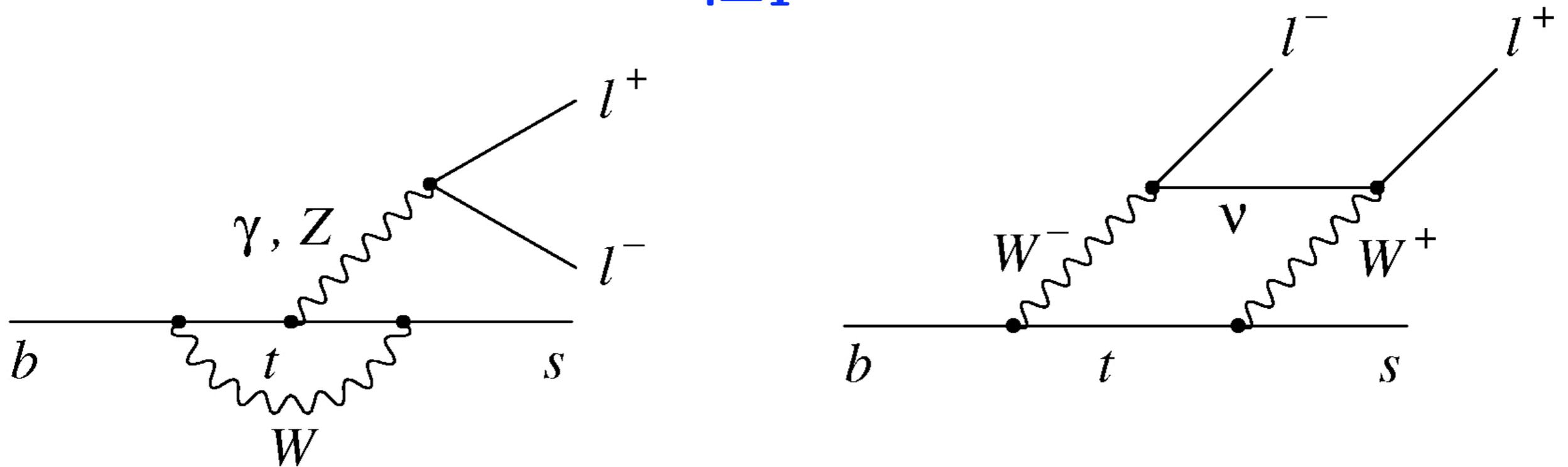
Photon spectrum moments from $B \rightarrow X_s \gamma$
contribute to determination of $|V_{cb}|$, b -quark mass,
and mean squared momentum of the b -quark:



$$b \rightarrow sl^+ l^-$$

Operator product expansion for $b \rightarrow sl^+l^-$:

$$\mathcal{H}_{\text{eff}} \propto \sum_{i=1}^{10} C_i \mathcal{O}_i$$



Short-distance Wilson coefficients:

$C_7^{\text{eff}} \approx 0.33$ from photon penguin

C_9^{eff} (C_{10}^{eff}) from vector (axial-vector) part of box

Branching ratios for $B \rightarrow K^{(*)} \ell^+ \ell^-$:



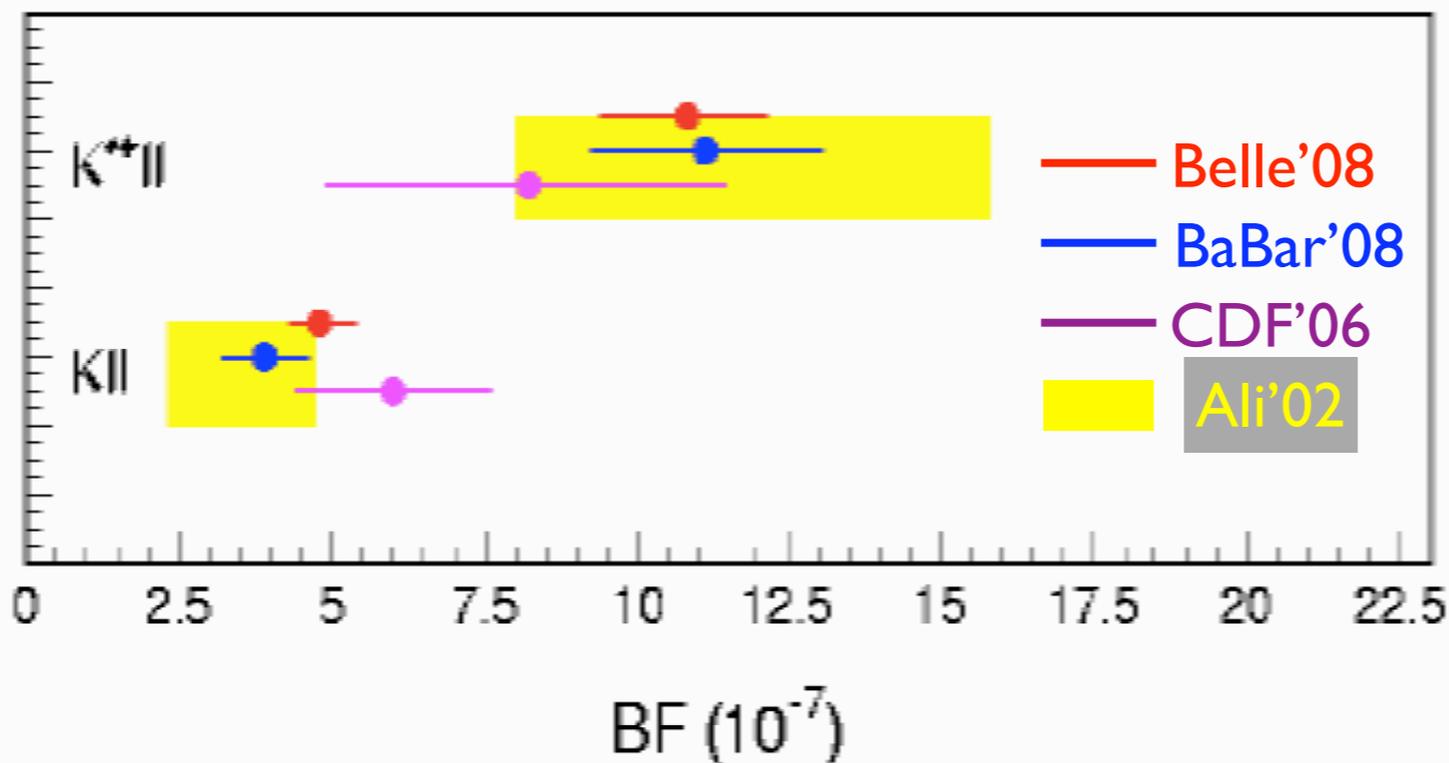
657M $B\bar{B}$ **New**

arXiv:0810.0335 (2008)

384M $B\bar{B}$ **New**

arXiv:0807.4119 (2008)

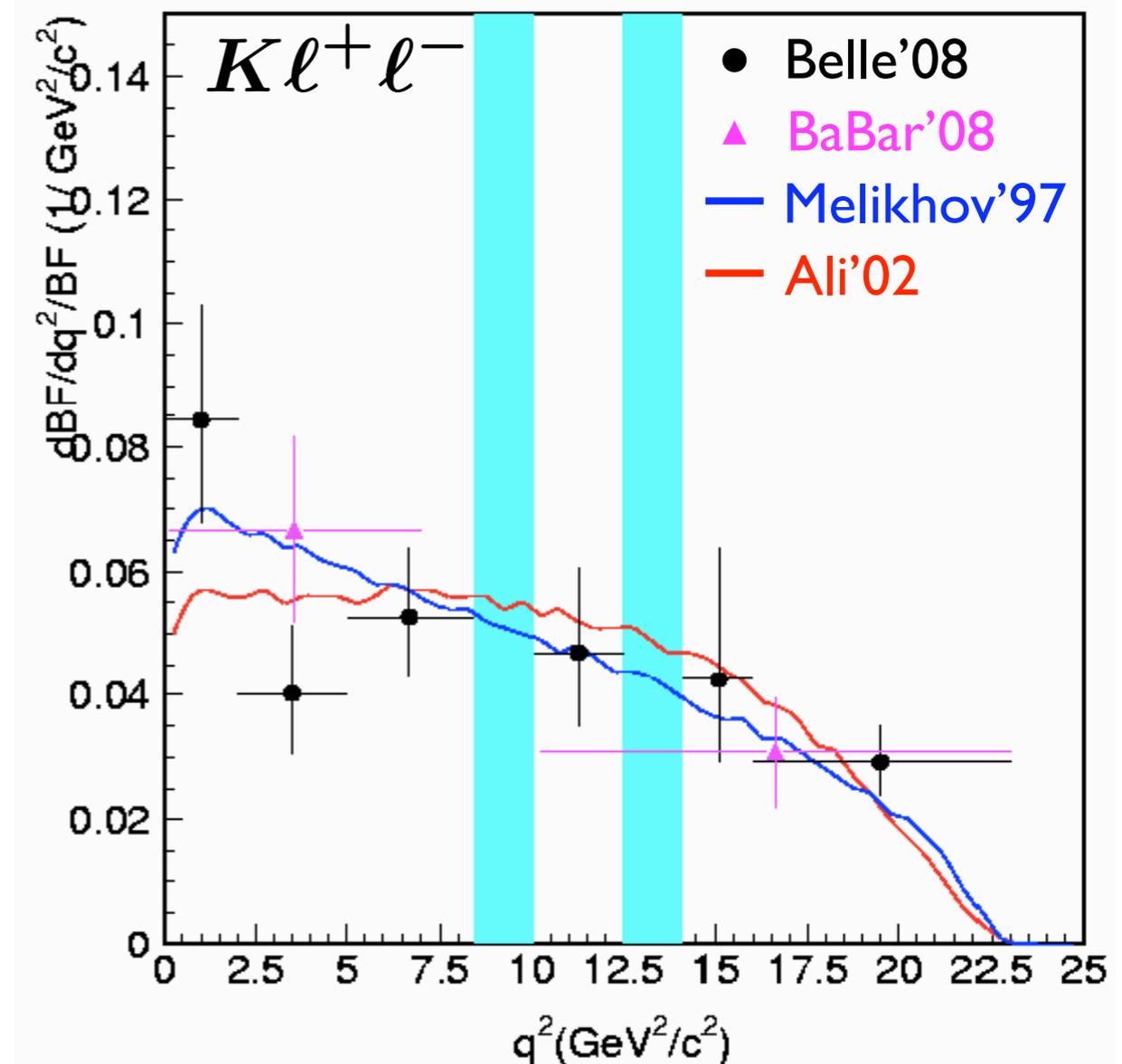
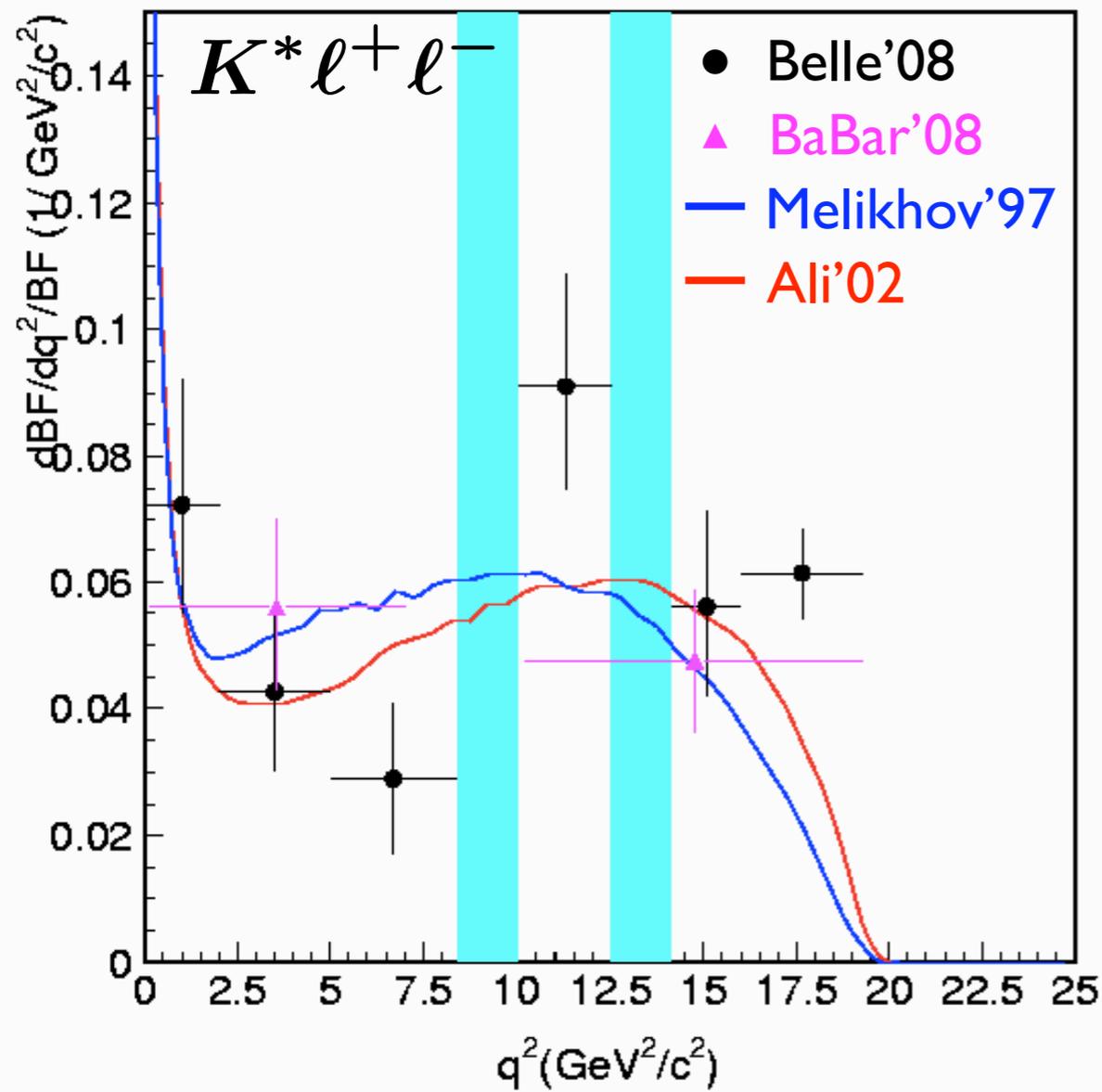
| Mode | $\mathcal{B}(\times 10^{-7})$ | $\mathcal{B}(\times 10^{-7})$ |
|---------------------|-------------------------------|-------------------------------|
| $K^* \ell^+ \ell^-$ | $10.8 \pm 1.0 \pm 0.9$ | $11.1 \pm 1.9 \pm 0.7$ |
| $K \ell^+ \ell^-$ | $4.8 \pm_{0.4}^{0.5} \pm 0.3$ | $3.9 \pm 0.7 \pm 0.2$ |



Consistent with SM expectations

Ali et al: PRD 66, 034002 (2002)
 Zhong et al: IJMO A18, 1959 (2003)

q^2 distributions in $B \rightarrow K^{(*)} \ell^+ \ell^-$:



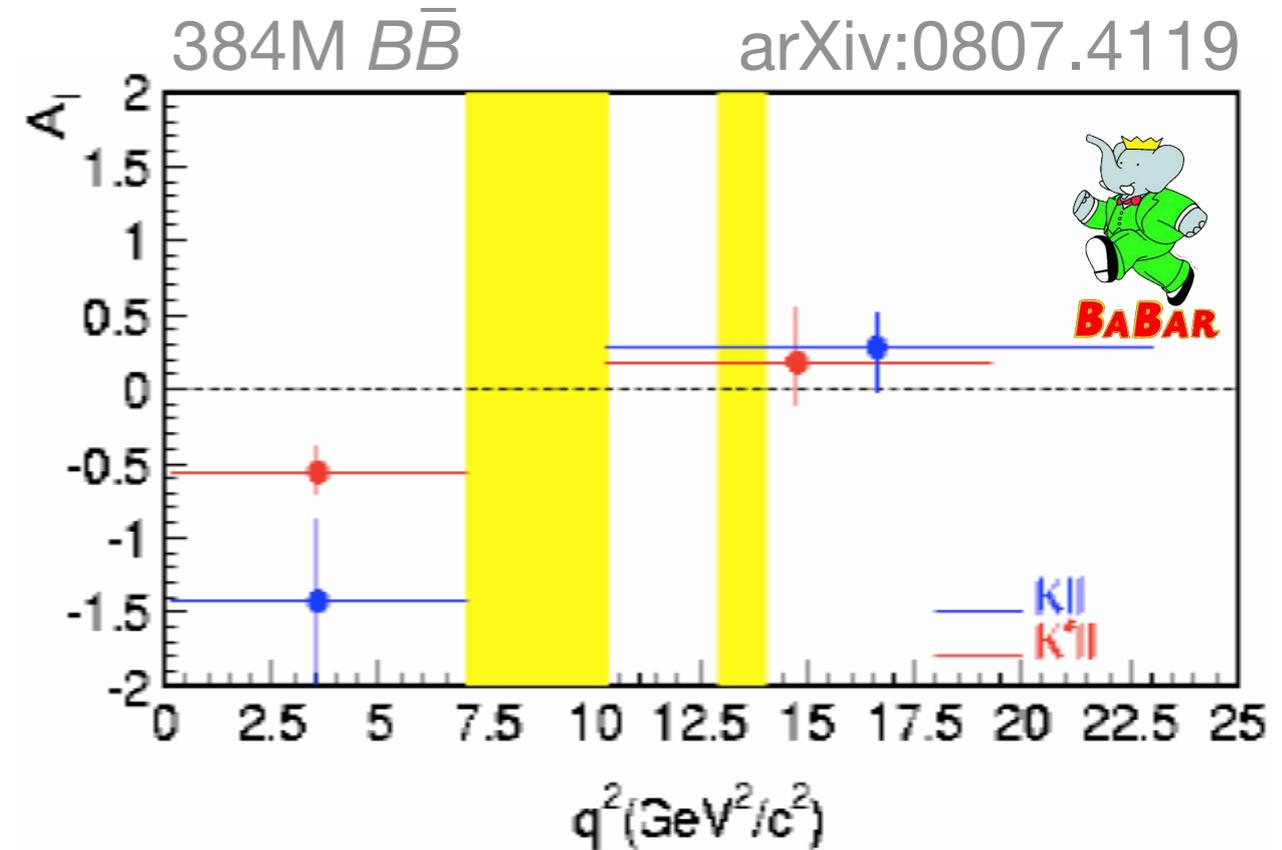
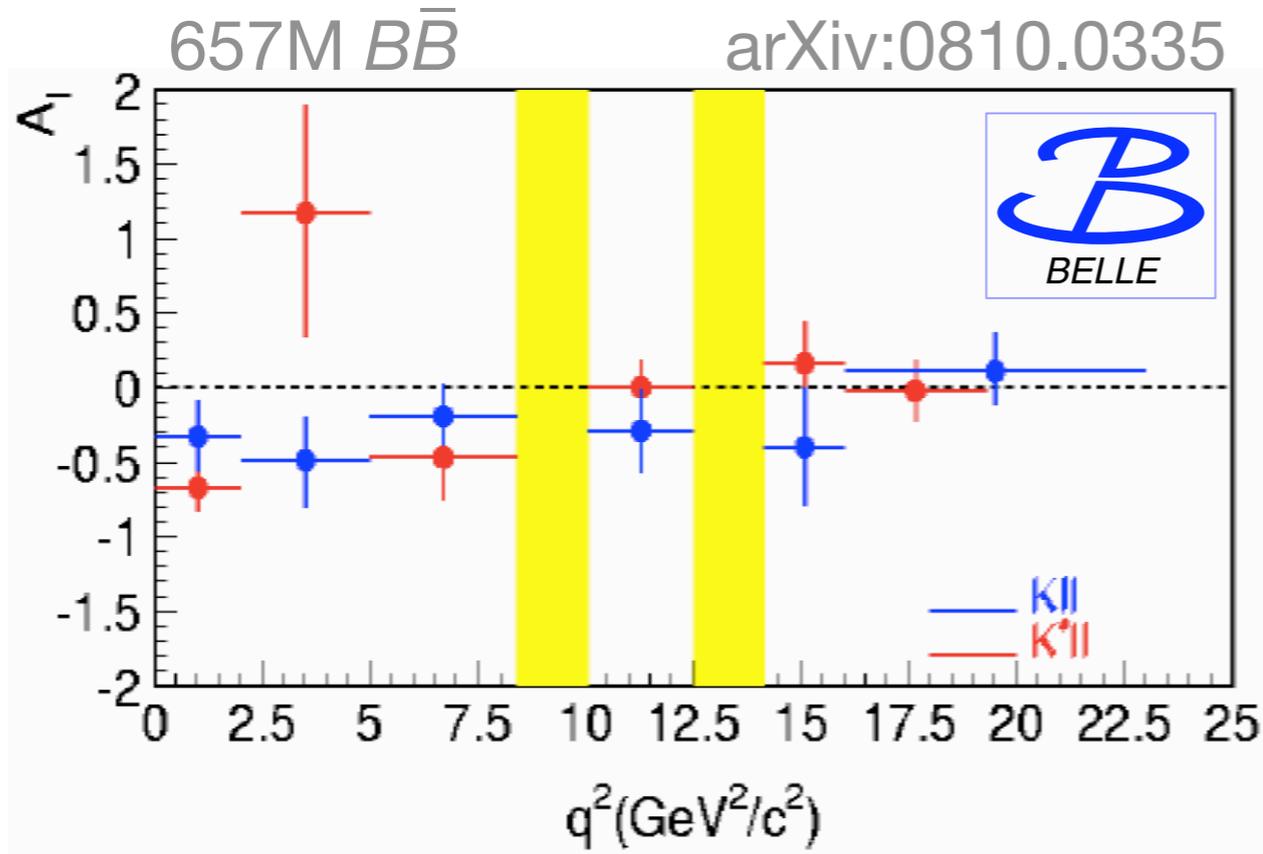
Consistent with SM expectations

Ali et al: PRD 66, 034002 (2002)

Melikhov et al: PLB 410, 290 (1997)

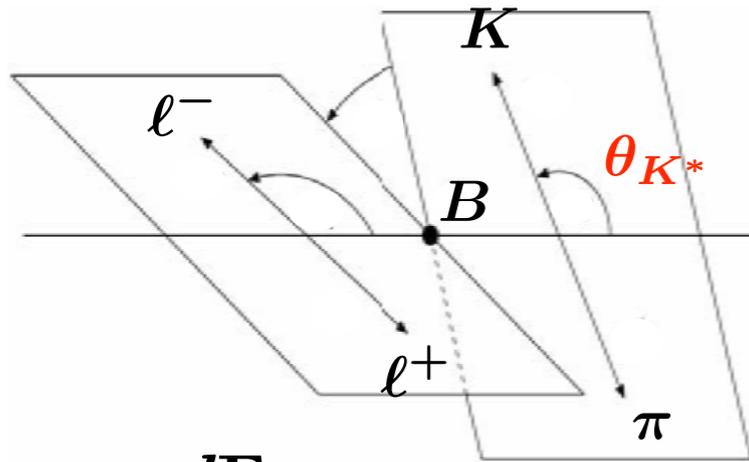
Isospin asymmetry in $B \rightarrow K^{(*)} \ell^+ \ell^-$:

$$A_I = \frac{1.071 \mathcal{B}(K^{(*)0} \ell \ell) - \mathcal{B}(K^{(*)\pm} \ell \ell)}{1.071 \mathcal{B}(K^{(*)0} \ell \ell) + \mathcal{B}(K^{(*)\pm} \ell \ell)}$$



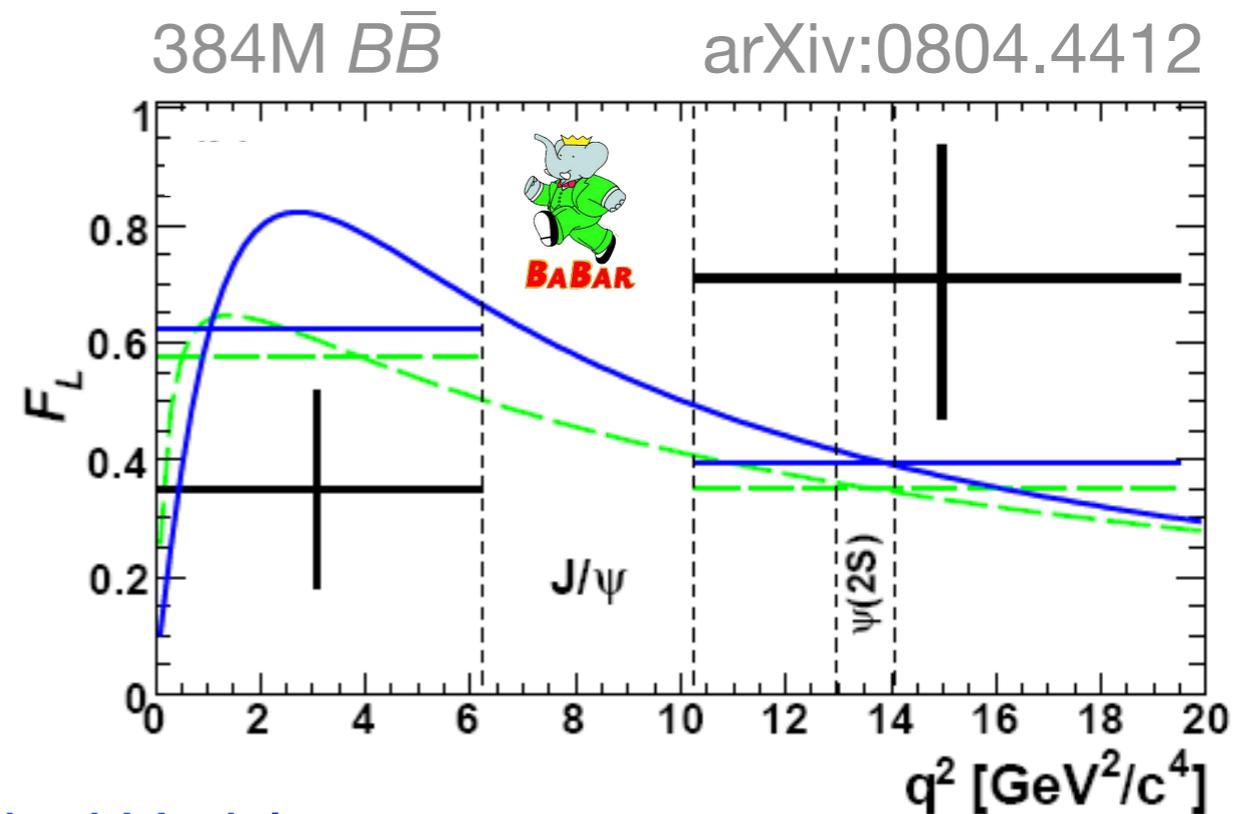
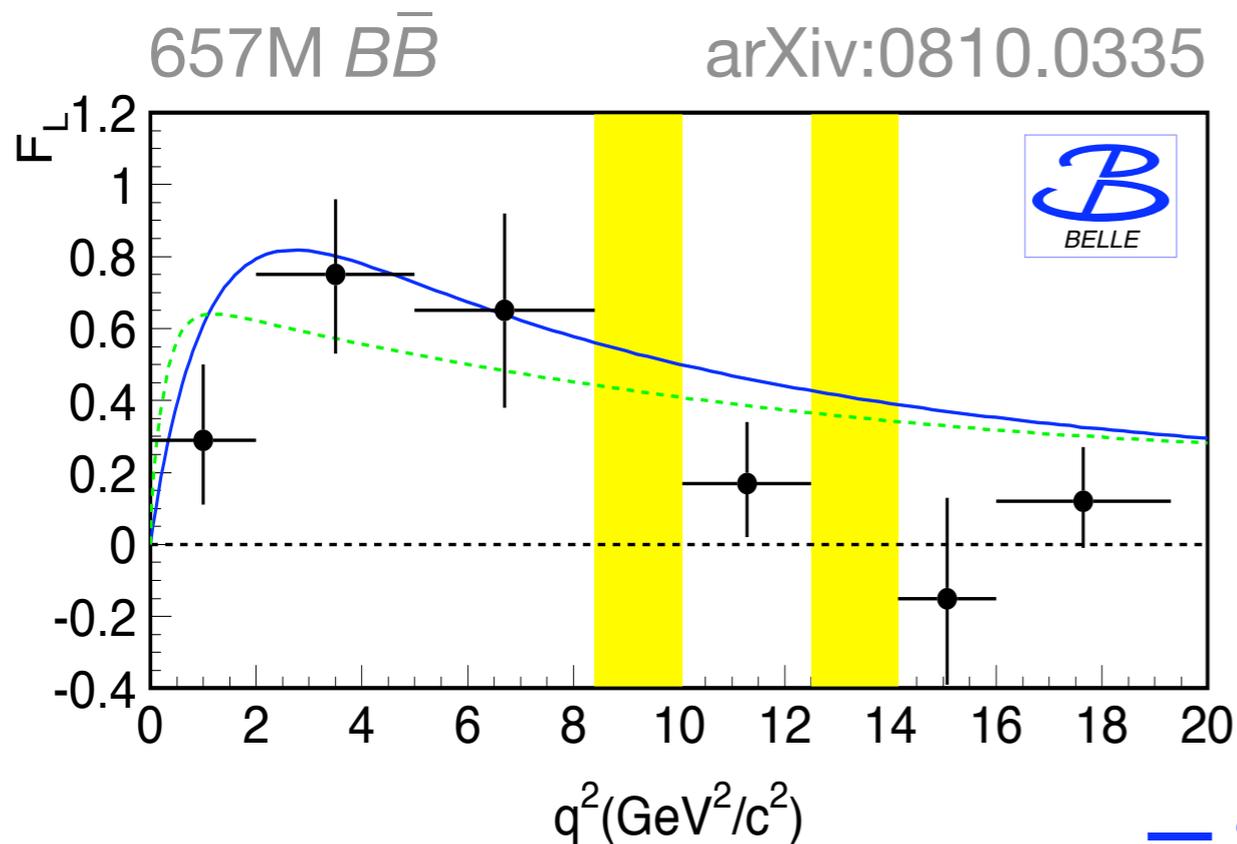
| Mode |  all q^2 |  all q^2 |
|---------------------|--|---|
| $K^* \ell \ell$ | $-0.29 \pm 0.16 \pm 0.03$ | $-0.12 \pm \begin{matrix} 0.18 \\ 0.16 \end{matrix} \pm 0.04$ |
| $K \ell \ell$ | $-0.31 \pm \begin{matrix} 0.17 \\ 0.14 \end{matrix} \pm 0.05$ | $-0.37 \pm \begin{matrix} 0.27 \\ 0.34 \end{matrix} \pm 0.04$ |
| $K^{(*)} \ell \ell$ | $-0.30 \pm \begin{matrix} 0.12 \\ 0.11 \end{matrix} \pm 0.04$ | $-0.18 \pm 0.15 \pm 0.03$ |

K^* longitudinal polarization in $B \rightarrow K^* \ell^+ \ell^-$:



Extracted from angular fit to θ_{K^*} in each q^2 bin.

$$\frac{d\Gamma}{d\cos\theta_{K^*}} = \frac{3}{2} F_L \cos^2 \theta_{K^*} + \frac{3}{4} (1 - F_L) \sin^2 \theta_{K^*}$$

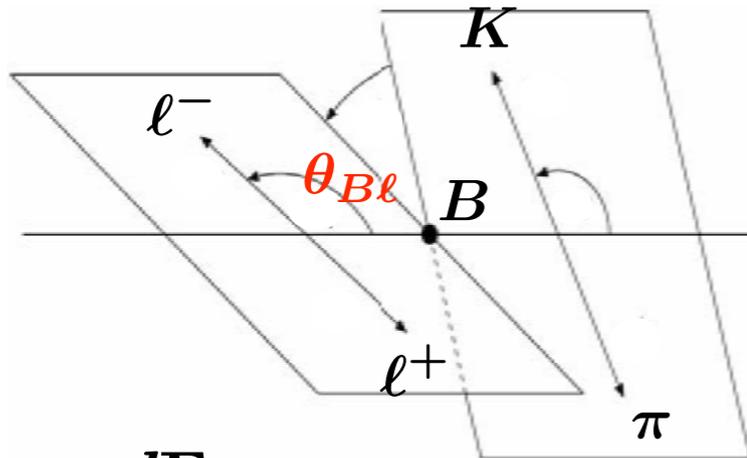


— Standard Model

— $C_7 = -C_7^{\text{SM}}$

Kruger and Matias: PRD 71, 094009 (2005)

Forward-backward asymmetry in $B \rightarrow K^* \ell^+ \ell^-$:

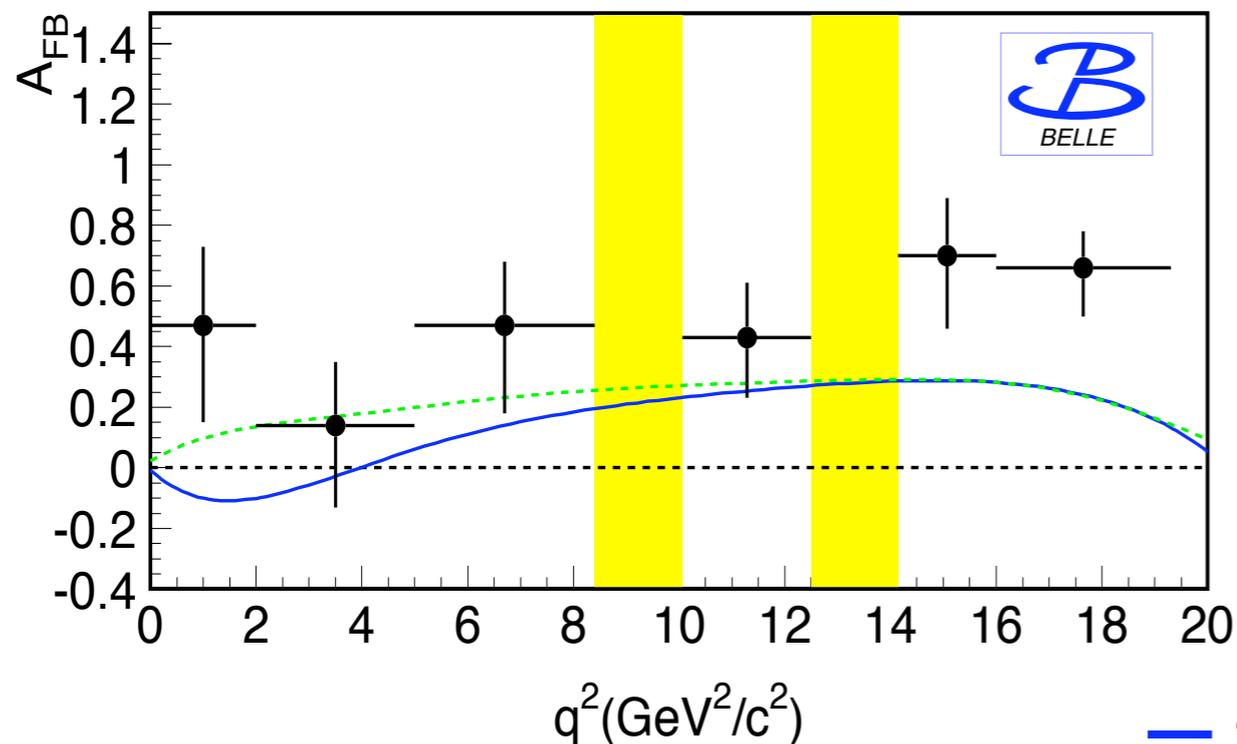


Extracted from angular fit to $\theta_{B\ell}$ in each q^2 bin.

$$\frac{d\Gamma}{d\cos\theta_{B\ell}} = \frac{3}{4}F_L \sin^2\theta_{B\ell} + \frac{3}{8}(1 - F_L)(1 + \cos^2\theta_{K^*}) + A_{FB} \cos\theta_{B\ell}$$

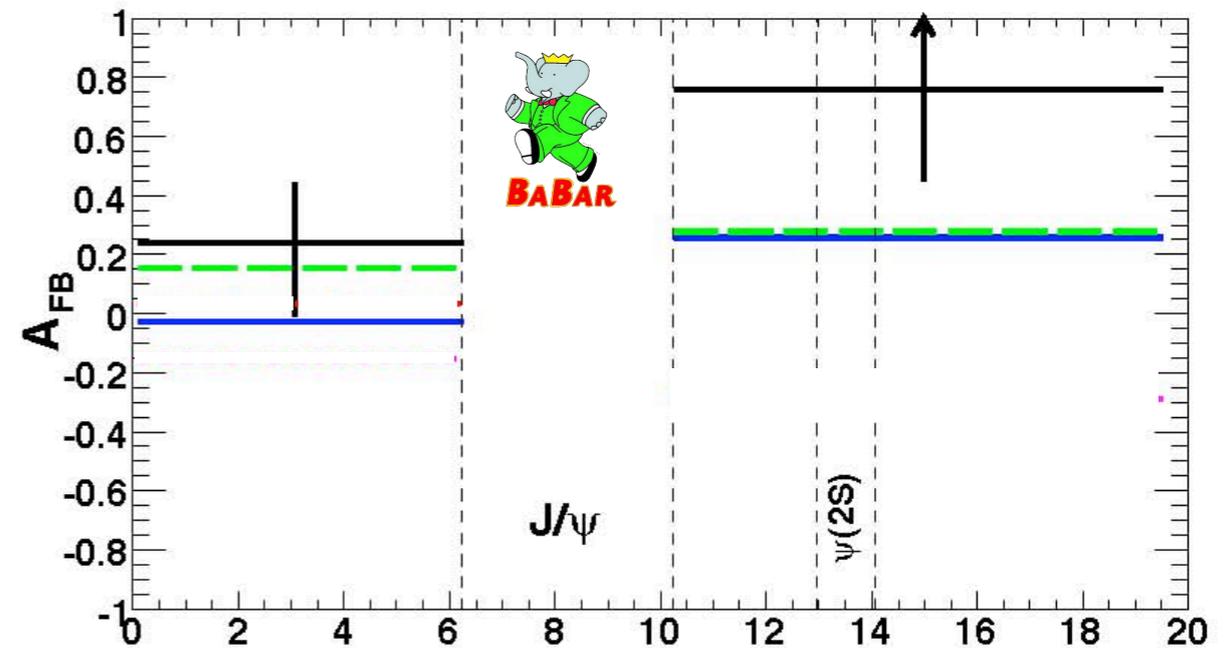
657M $B\bar{B}$

arXiv:0810.0335



384M $B\bar{B}$

arXiv:0804.4412

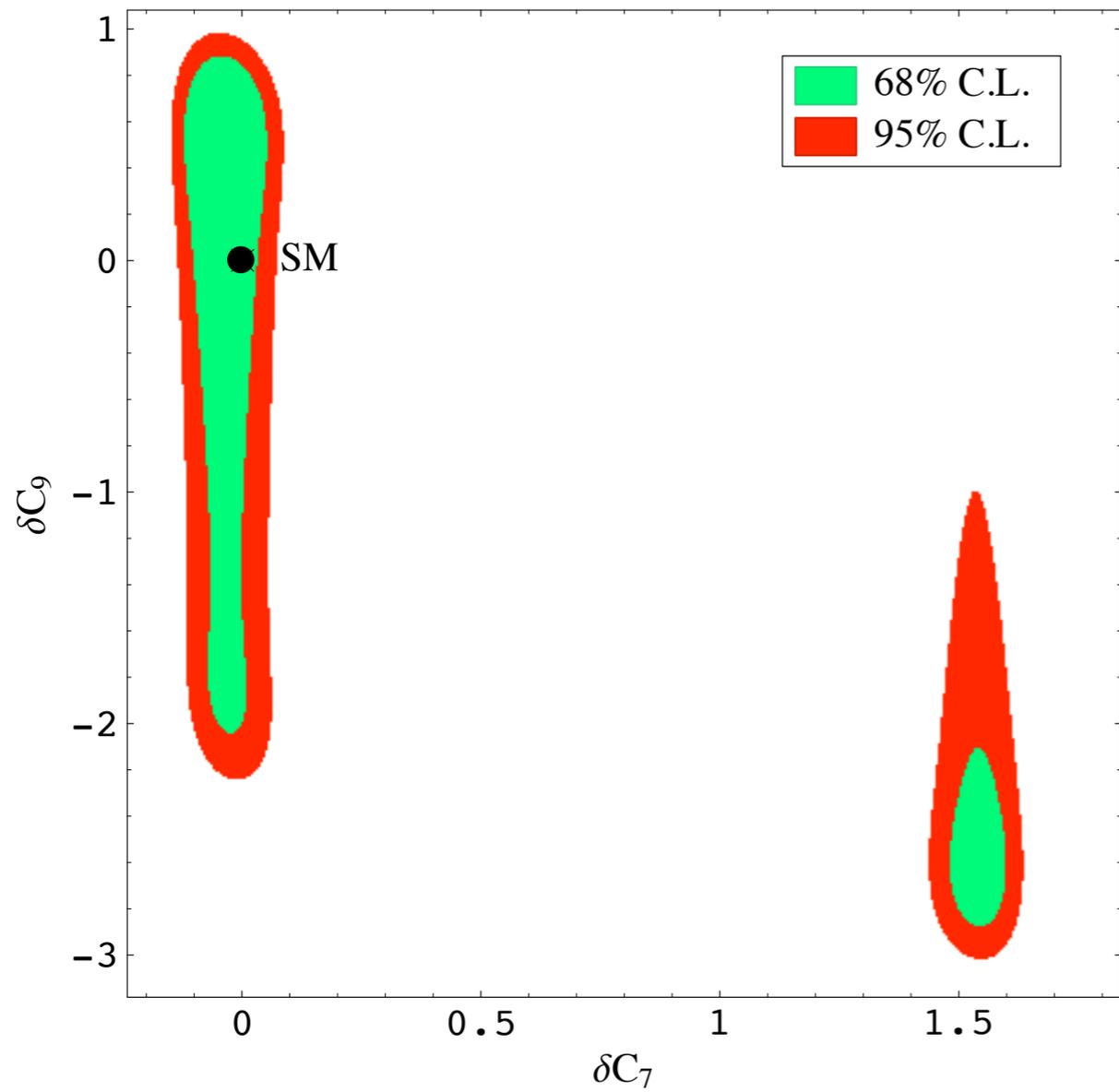


— Standard Model

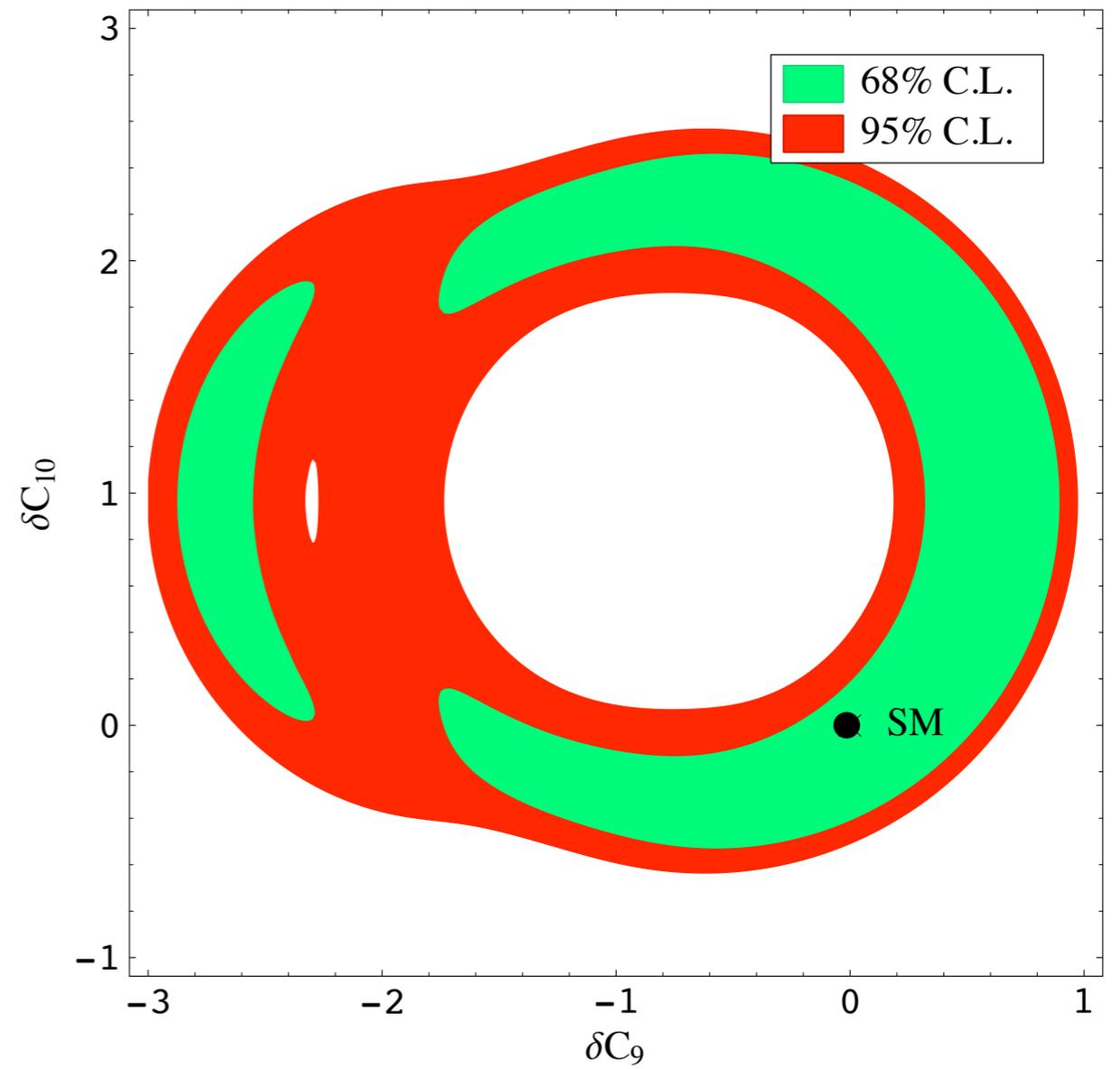
— $C_7 = -C_7^{\text{SM}}$

Kruger and Matias: PRD 71, 094009 (2005)

Correlations of C_7 , C_9 , and C_{10} new-physics shifts

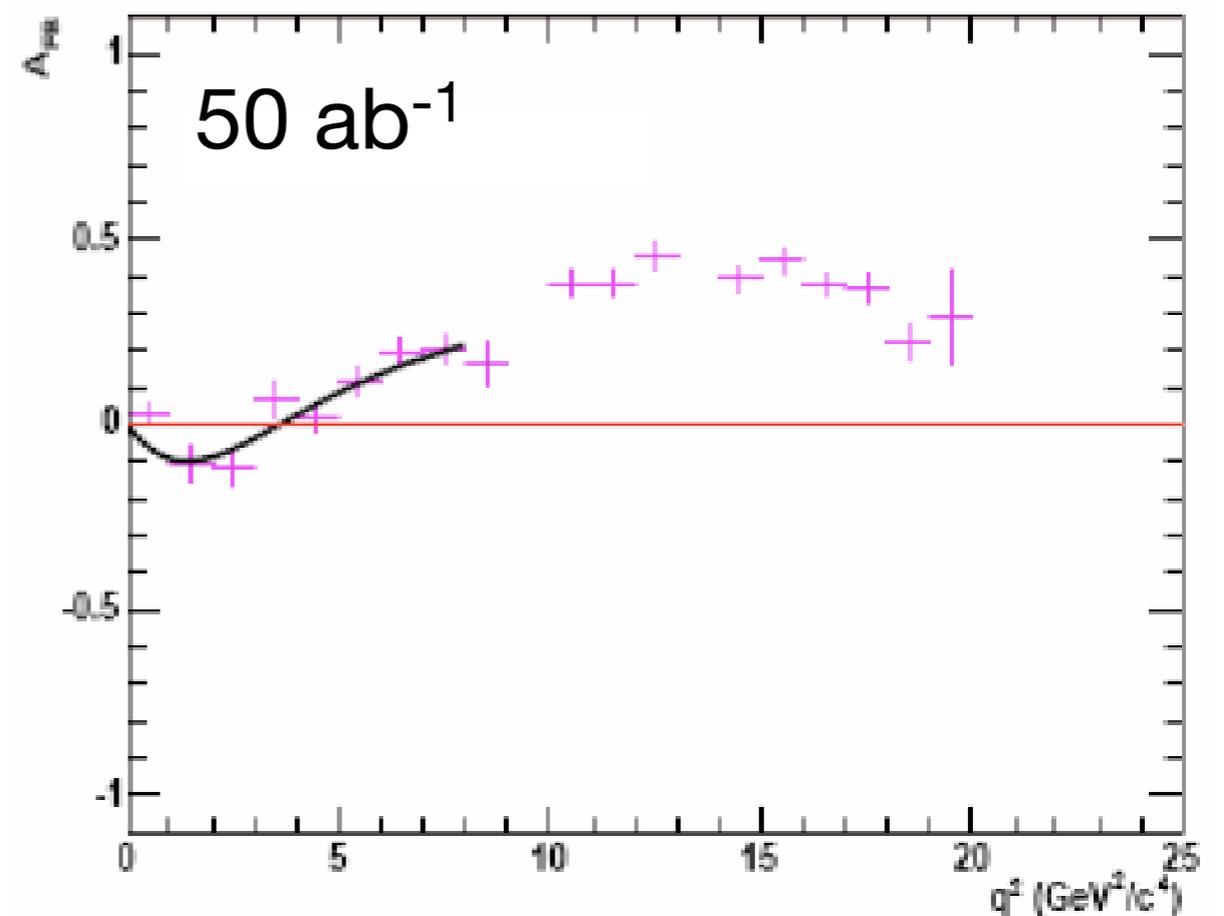
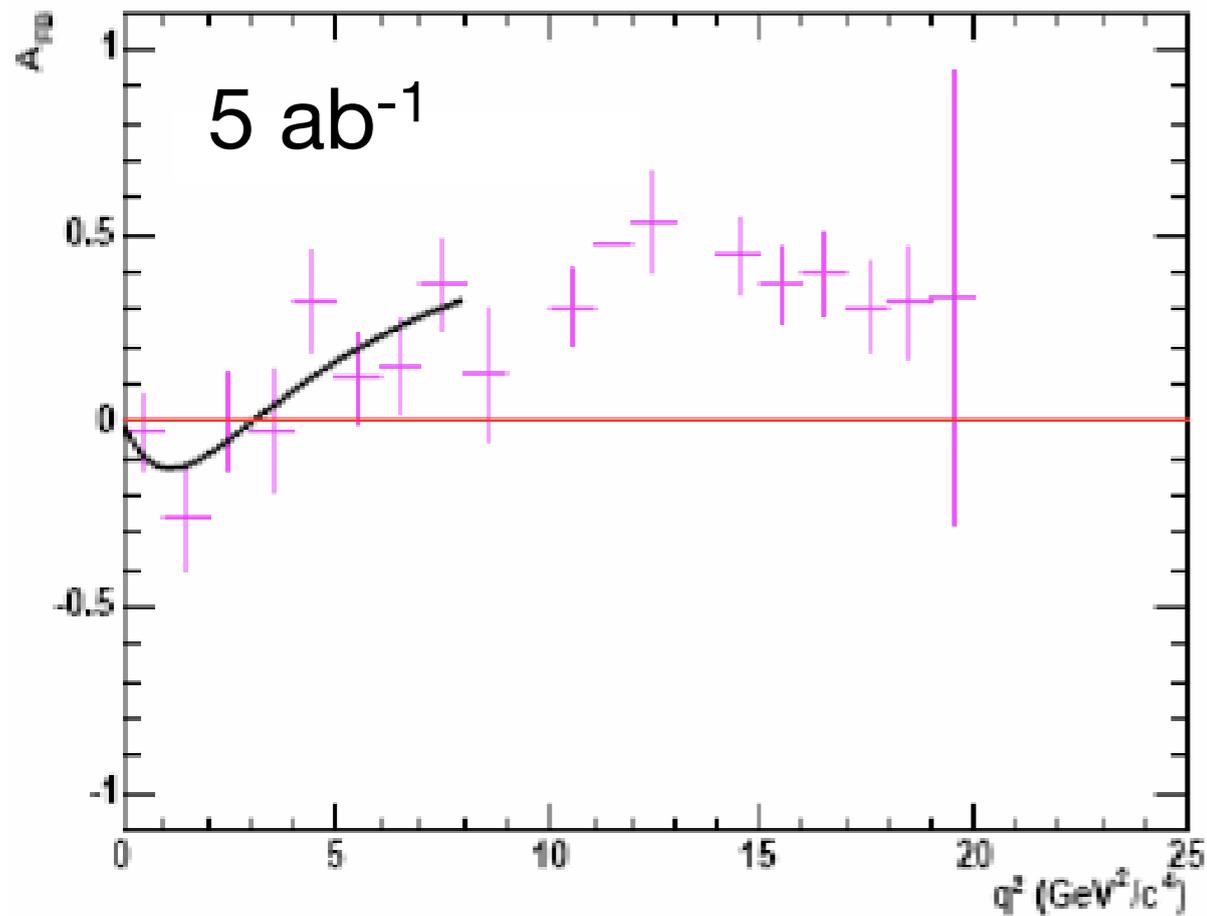


Kamenik: arXiv 0805.2363 (2008)



Forward-backward asymmetry in $B \rightarrow K^* \ell^+ \ell^-$:

Future prospects at a Super-B Factory:



$b \rightarrow s \cancel{CP}$

$b \rightarrow s\gamma$ and $b \rightarrow sq\bar{q}$

summary only

Charge asymmetry (direct \mathcal{CP}) in $B \rightarrow K^* \gamma$:

$$A_{CP} = \frac{\Gamma(\bar{B} \rightarrow \bar{K}^* \gamma) - \Gamma(B \rightarrow K^* \gamma)}{\Gamma(\bar{B} \rightarrow \bar{K}^* \gamma) + \Gamma(B \rightarrow K^* \gamma)}$$



$$A_{CP} = -0.009 \pm 0.017 \pm 0.011$$

arXiv:0808.1915 (2008) 347M $B\bar{B}$

New



$$A_{CP} = -0.015 \pm 0.044 \pm 0.012$$

PRD 69, 112001 (2004) 85M $B\bar{B}$

... consistent with SM expectation of $A_{CP} < 0.01$

Greub, Simma, Wyler: Nucl Phys B 434, 39 (1995)

Isospin asymmetry in $B \rightarrow K^* \gamma$:

$$\Delta_{0+} = \frac{\Gamma(B^0 \rightarrow K^{*0} \gamma) - \Gamma(B^+ \rightarrow K^{*+} \gamma)}{\Gamma(B^0 \rightarrow K^{*+} \gamma) + \Gamma(B^+ \rightarrow K^{*+} \gamma)}$$

Assuming $f_+/f_0 = 1.020 \pm 0.034$ for the B^+/B^0 production ratio,

$$\Delta_{0+} = +0.029 \pm 0.019 \pm 0.016 \pm 0.018$$



arXiv:0808.1915 (2008) 347M $B\bar{B}$

New

Assuming $f_+/f_0 = 1.044 \pm 0.050$ for the B^+/B^0 production ratio,

$$\Delta_{0+} = +0.034 \pm 0.044 \pm 0.026 \pm 0.025$$

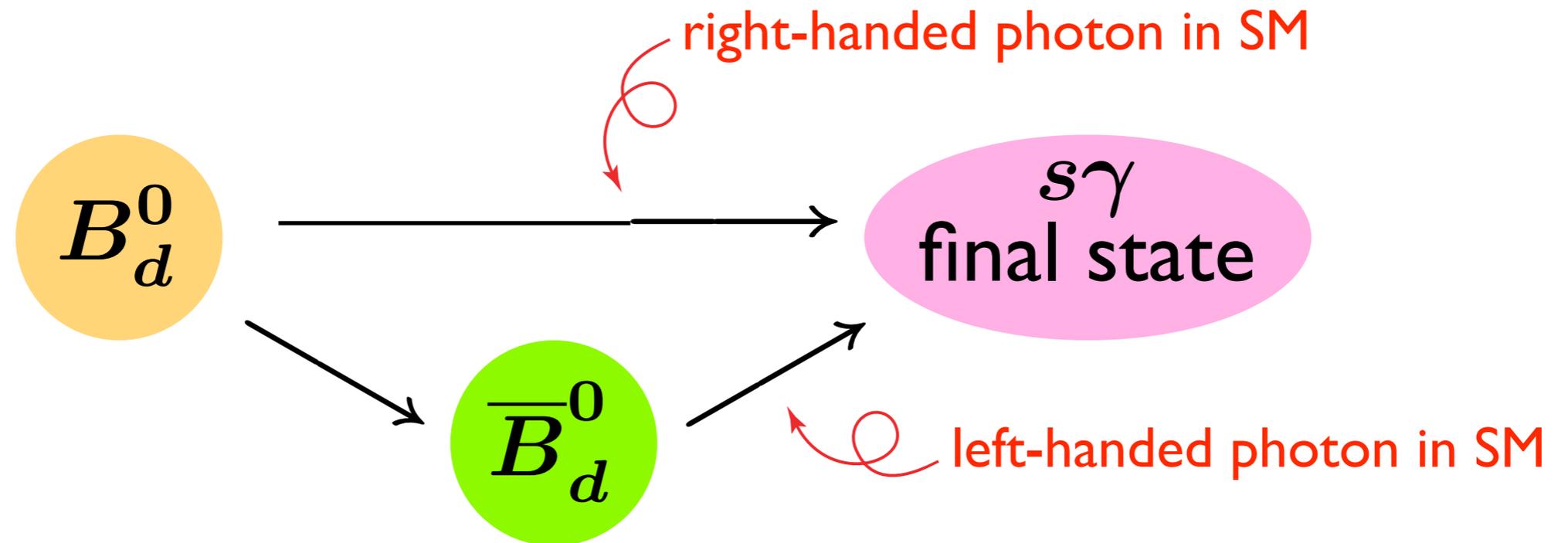


PRD 69, 112001 (2004) 85M $B\bar{B}$

... consistent with SM exp of $\Delta_{0+} = +0.026 \pm 0.008$

Matsumori, Sanda, Keum: PRD 72, 014013 (2005)

Time-dependent CP asymmetry in $b \rightarrow s\gamma$:



For 100% photon polarization, there is no common $s\vec{\gamma}$ final state \Rightarrow no time-dependent CP in SM.

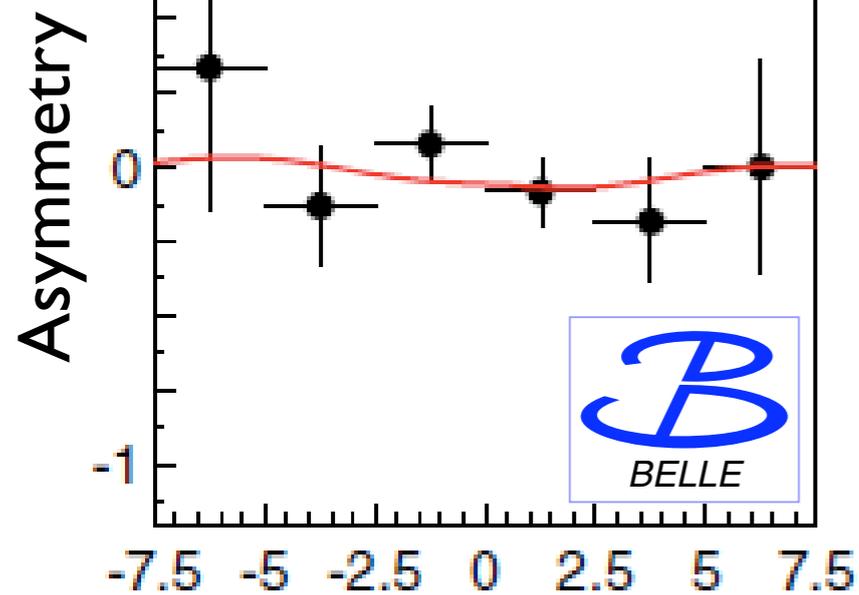
For $B^0 \rightarrow K_S \pi^0 \gamma$, $S \approx -2(m_s/m_b) \sin(2\phi_1)$.

New physics with alternate helicity structure can give time-dependent CP without affecting $\Gamma(b \rightarrow s\gamma)$.

Atwood, Soni, Gronau: PRL 79, 185 (1997)

Atwood, Gershon, Hazumi, Soni: PRD 71, 076003 (2005)

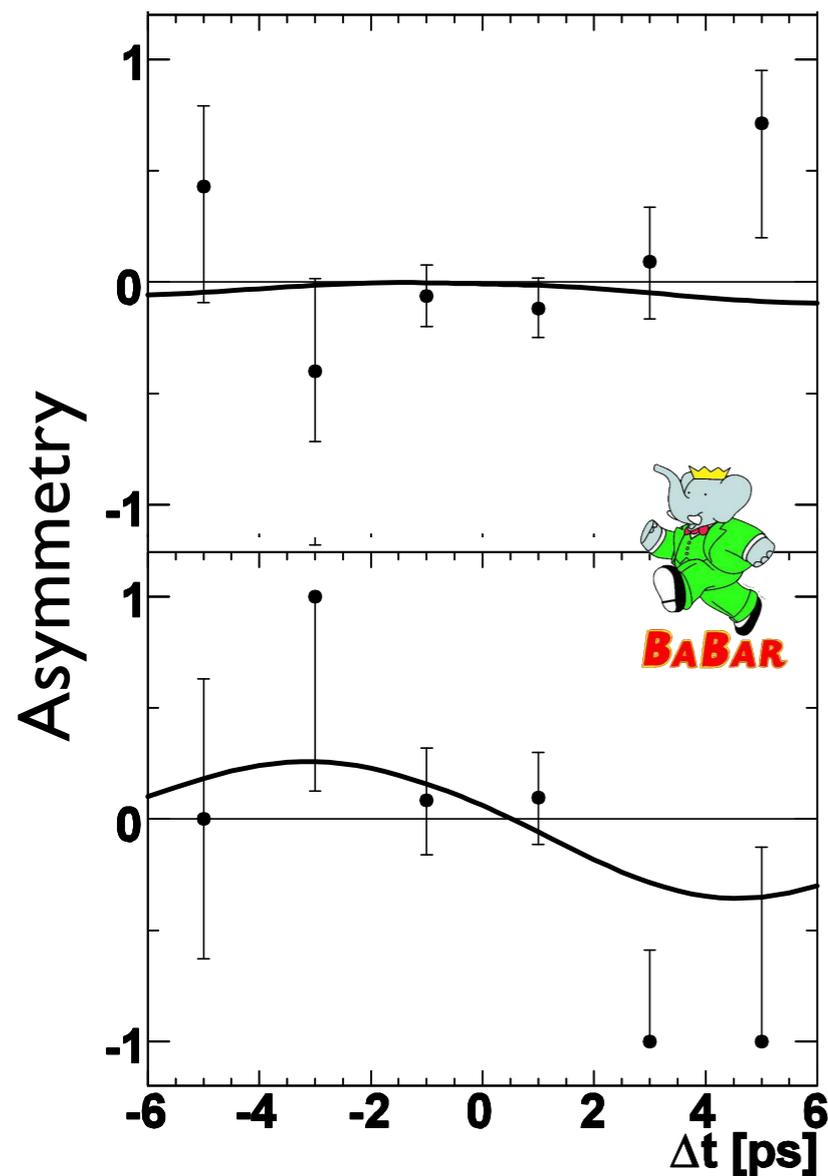
Time-dependent CP asymmetry in $B^0 \rightarrow K_S \pi^0 \gamma$:



K^* and non- K^* region ($M_{K\pi} < 1.8$ GeV)

$$K^* \gamma \begin{cases} S = -0.10 \pm 0.31 \pm 0.07 \\ A = -0.20 \pm 0.20 \pm 0.06 \end{cases}$$

535M $B\bar{B}$ PRD 74, 111104(R) (2006)



K^* region ($0.8 < M_{K\pi} < 1.0$ GeV)

$$K^* \gamma \begin{cases} S = -0.03 \pm 0.29 \pm 0.03 \\ C = -0.14 \pm 0.06 \pm 0.03 \equiv -A \end{cases}$$

New

465M $B\bar{B}$ arXiv:0807.3103 (2008)

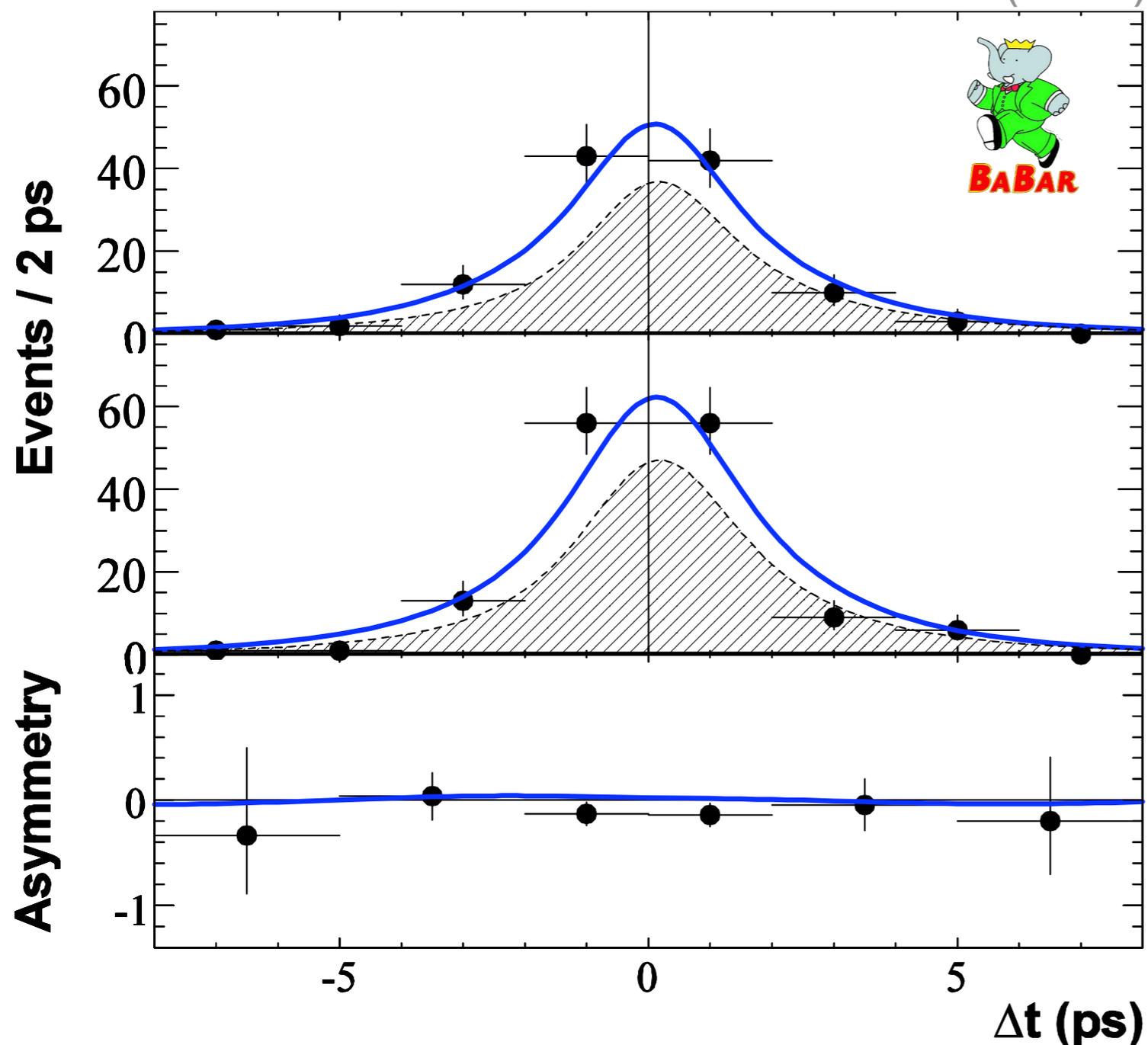
non- K^* region ($1.1 < M_{K\pi} < 1.8$ GeV)

Consistent with no \mathcal{CP}

Time-dependent CP asymmetry in $B^0 \rightarrow K_S \eta \gamma$:

465M $B\bar{B}$

arXiv:0805.1317 (2008)



New

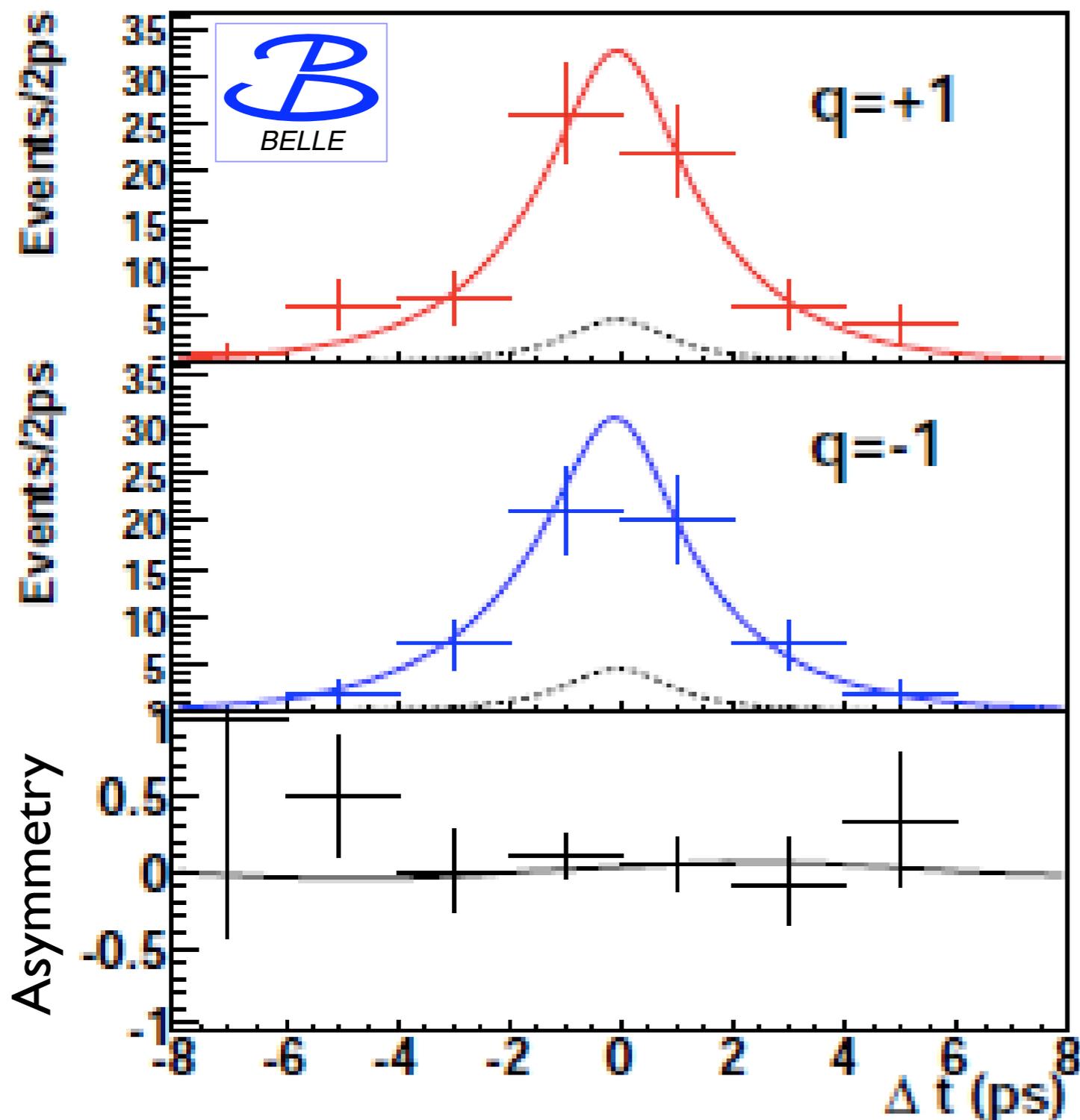
$$S = 0.18 \pm \begin{matrix} 0.49 \\ 0.46 \end{matrix} \pm 0.12$$
$$C = -0.32 \pm \begin{matrix} 0.40 \\ 0.39 \end{matrix} \pm 0.07$$

Consistent with no CP

Time-dependent CP asymmetry in $B^0 \rightarrow K_S \rho^0 \gamma$:

657M $B\bar{B}$

arXiv:0806.1980 (2008)



For events in the region

$$M_{K\pi^+\pi^-} < 1.8 \text{ GeV}$$

$$0.6 < M_{\pi^+\pi^-} < 0.9 \text{ GeV}$$

$$S_{\text{eff}} = 0.09 \pm 0.27 \pm 0.04$$

$$A_{\text{eff}} = 0.35 \pm 0.18 \pm 0.06$$

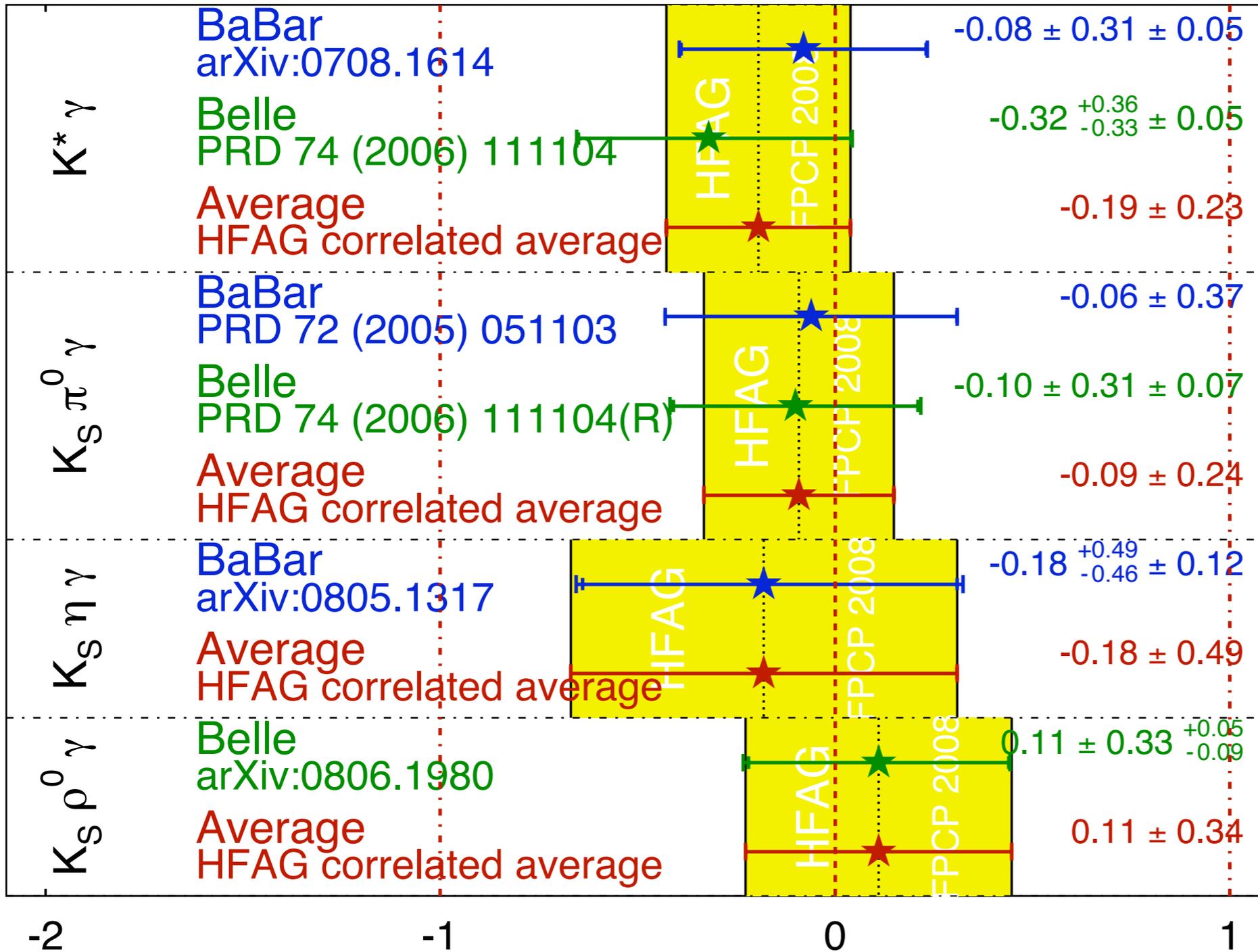
$$S = 0.11 \pm 0.33 \pm 0.05$$

New

Consistent with no CP

$b \rightarrow s \gamma$ S_{CP}

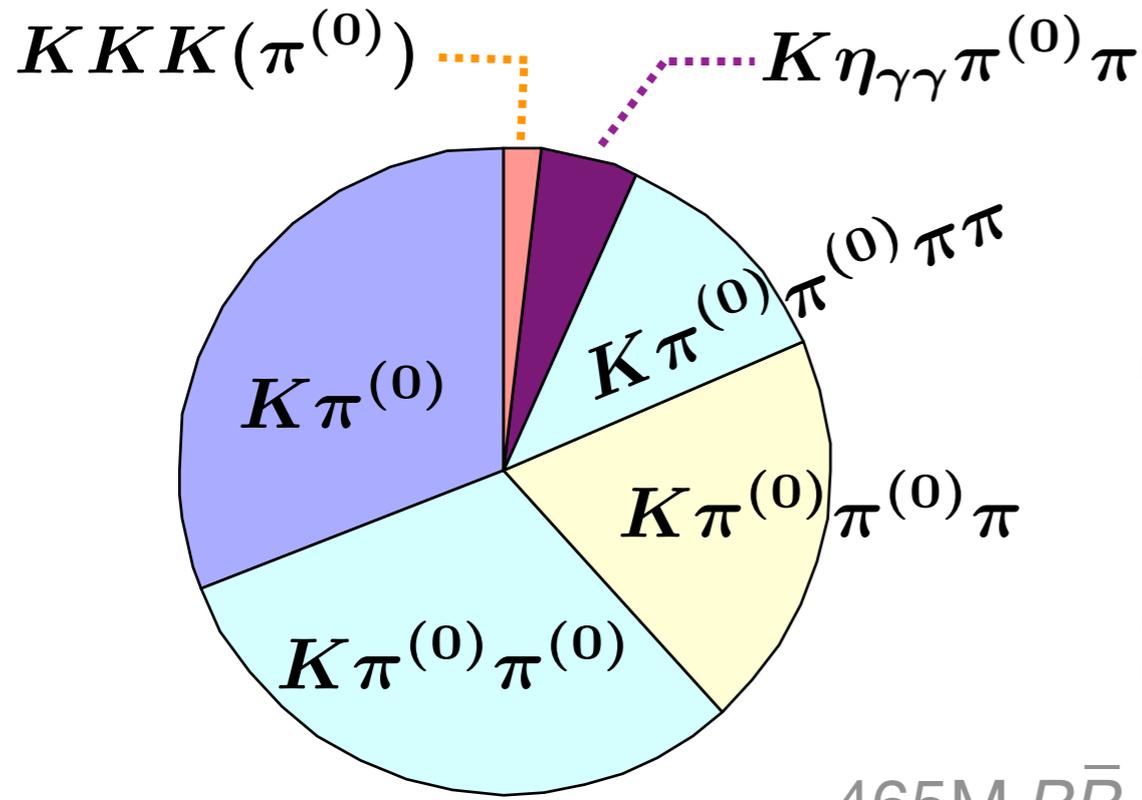
HFAG
FPCP 2008
PRELIMINARY



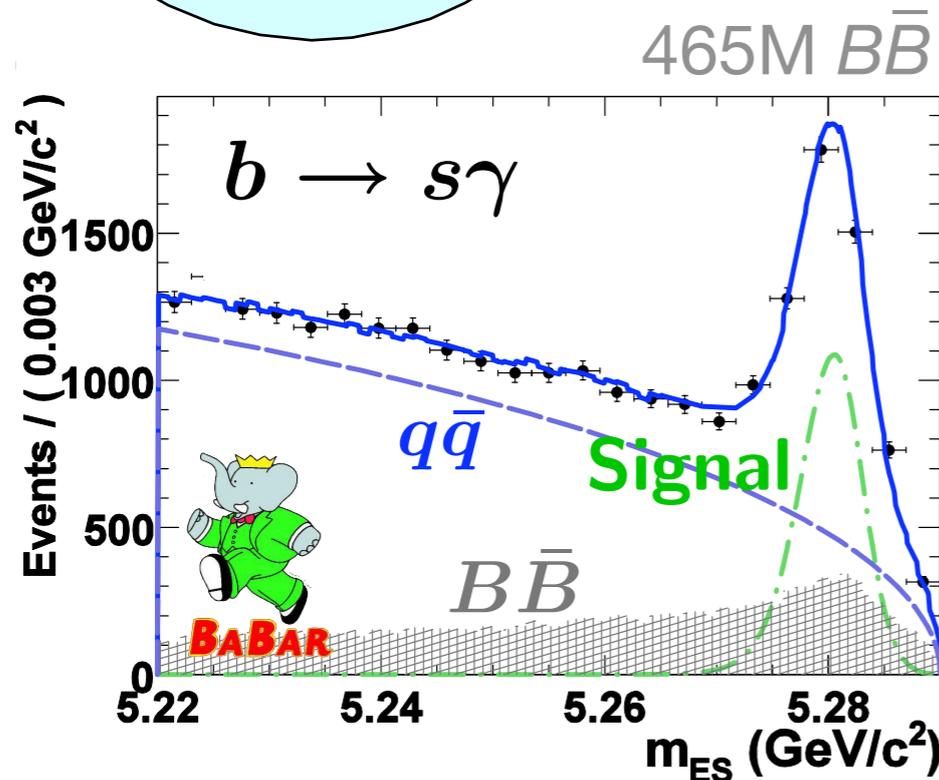
◀ $-0.03 \pm 0.29 \pm 0.03$
arXiv:0807.3103 (2008)

◀ $0.18 \pm 0.49 \pm 0.12$
arXiv:0805.1317 (2008)

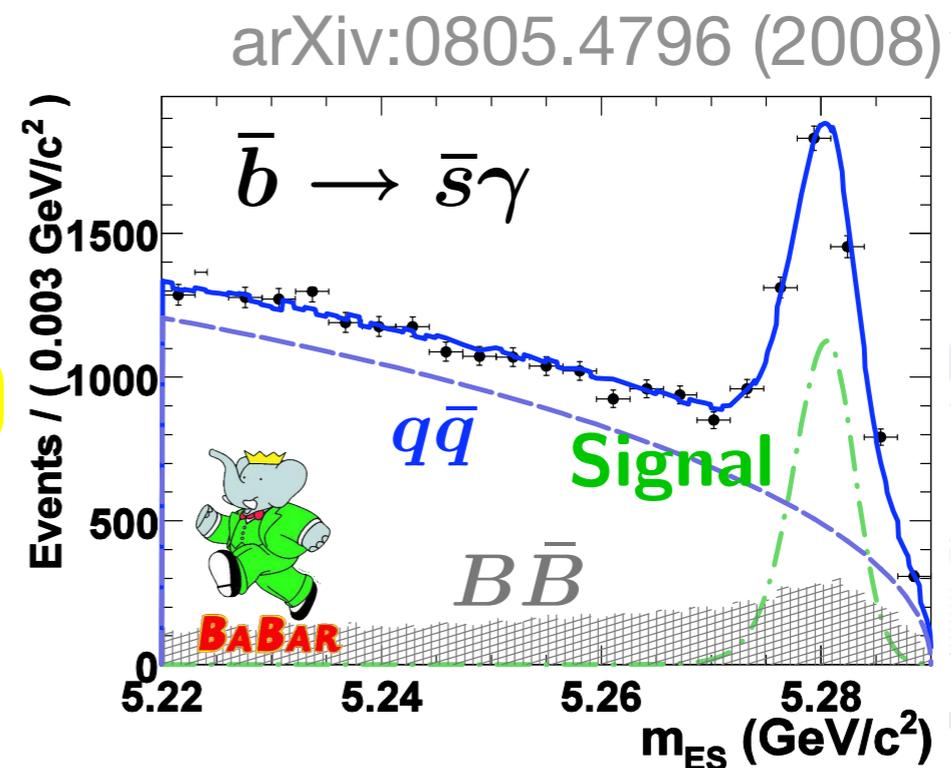
Time-integrated CP asymmetry in $B \rightarrow X_s \gamma$:



Reconstruct X_s using 16 exclusive final states (~55% of all possible X_s states).
Self-tagging.



New



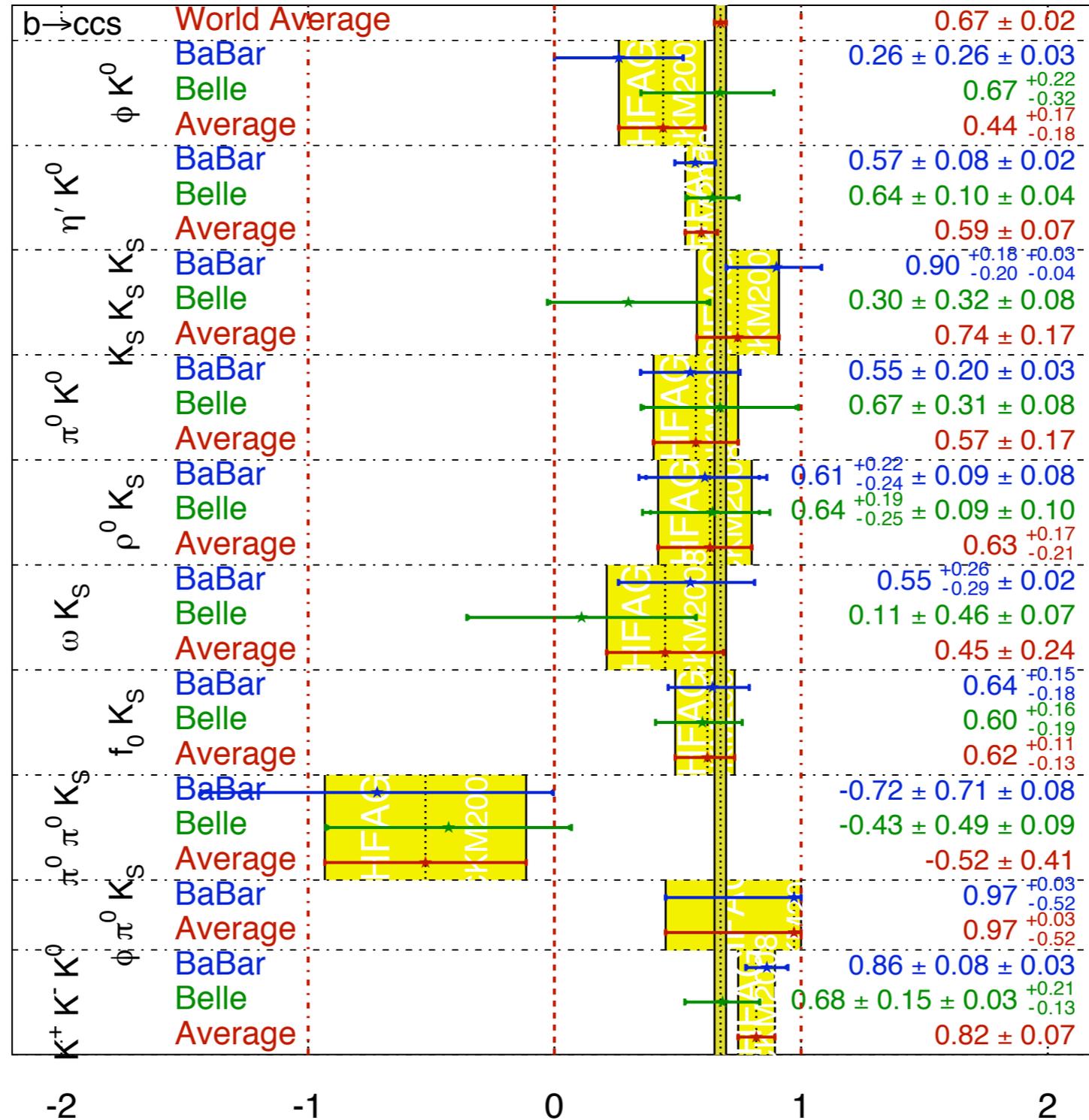
$$A_{CP} = -0.011 \pm 0.030 \pm 0.014$$

Consistent with no CP

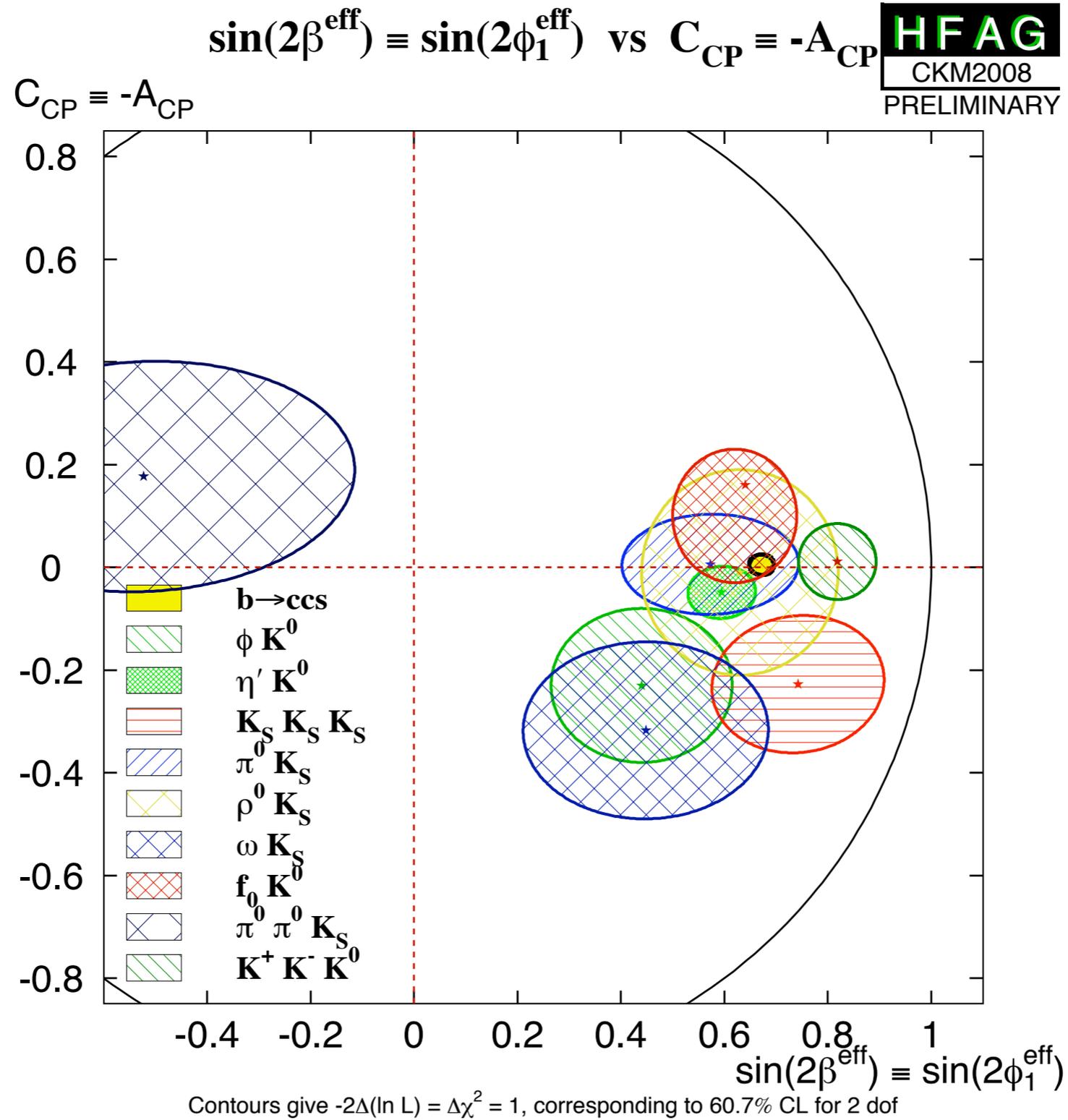
Time-dependent CP asymmetry in $b \rightarrow sq\bar{q}$:

$$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$$

HFAG
CKM2008
PRELIMINARY



Time-dependent CP asymmetry in $b \rightarrow sq\bar{q}$:



Conclusions:

- No evidence so far for new physics
- Need more data to improve the sensitivity to new physics of these rare processes (Super B!)

I am indebted to the following colleagues in Belle and BaBar, from whose talks at ICHEP and elsewhere the material presented here was obtained:



Jin Li, Antonio Limosani, Jui-Te Wei,
Shohei Nishida, Miyuki Fujikawa



Colin Jessop, Kevin Flood, James Hirschauer

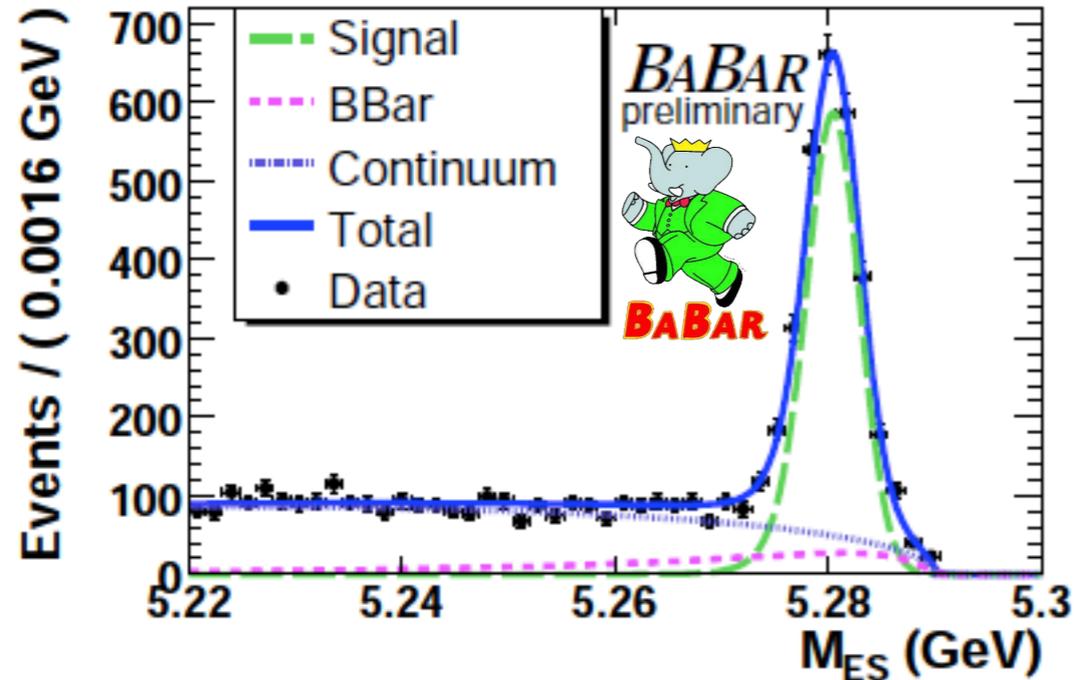
Extra

Branching ratios for $B \rightarrow K^* \gamma$:

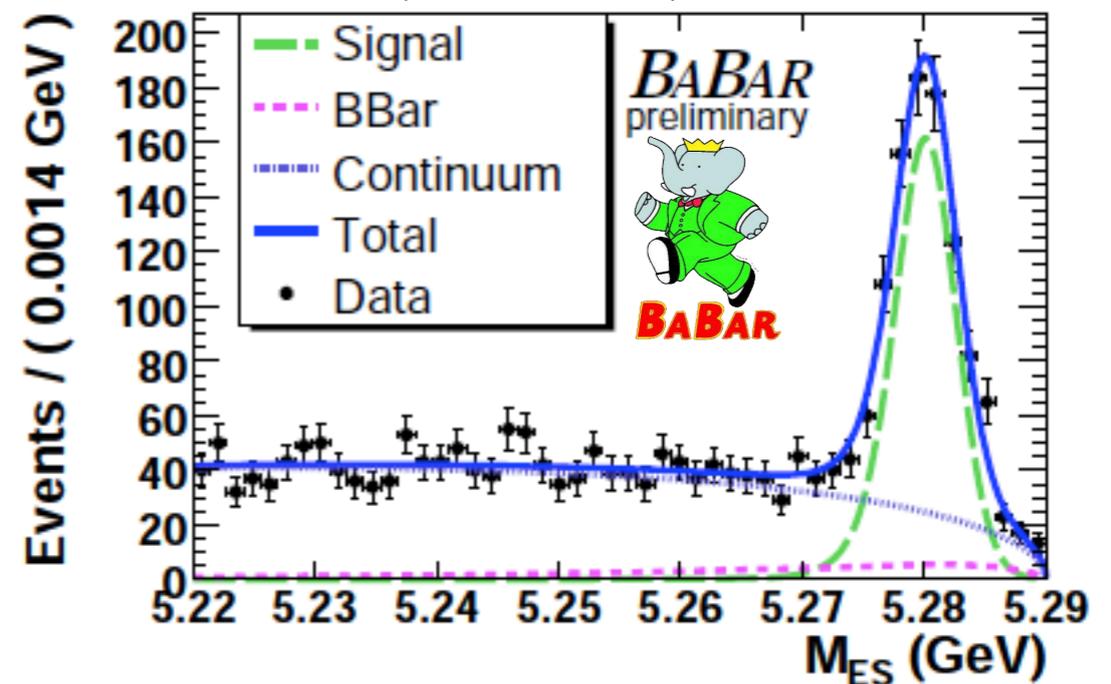
383M $B\bar{B}$

arXiv:0808.1915

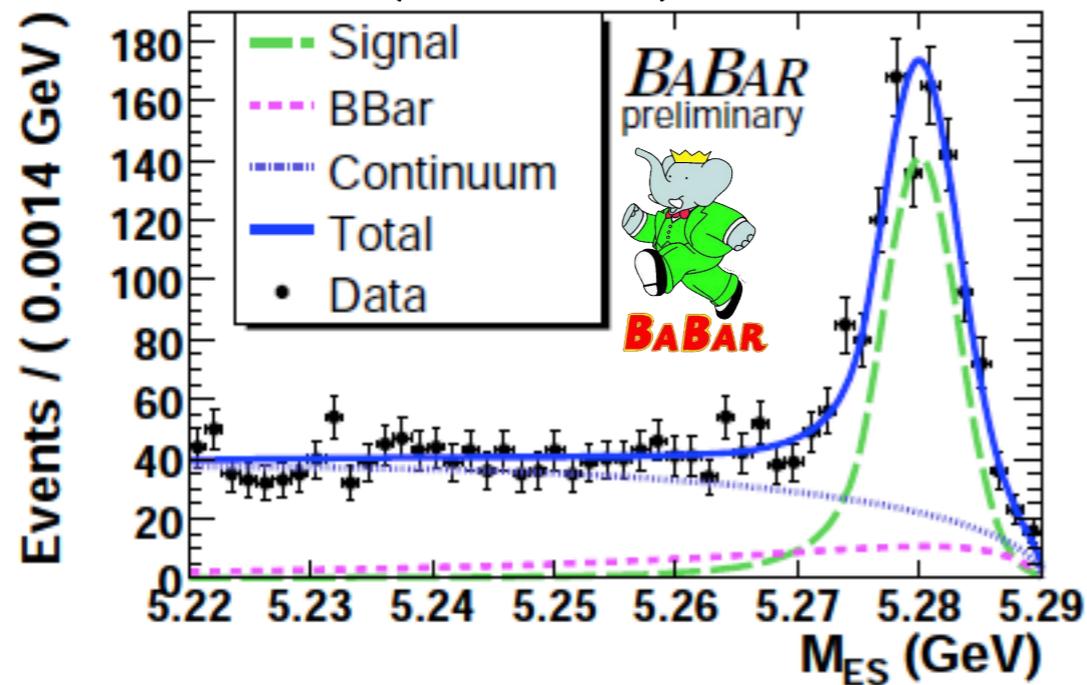
$$K^{*0} (K^+ \pi^-) \gamma$$



$$K^{*+} (K_S \pi^+) \gamma$$

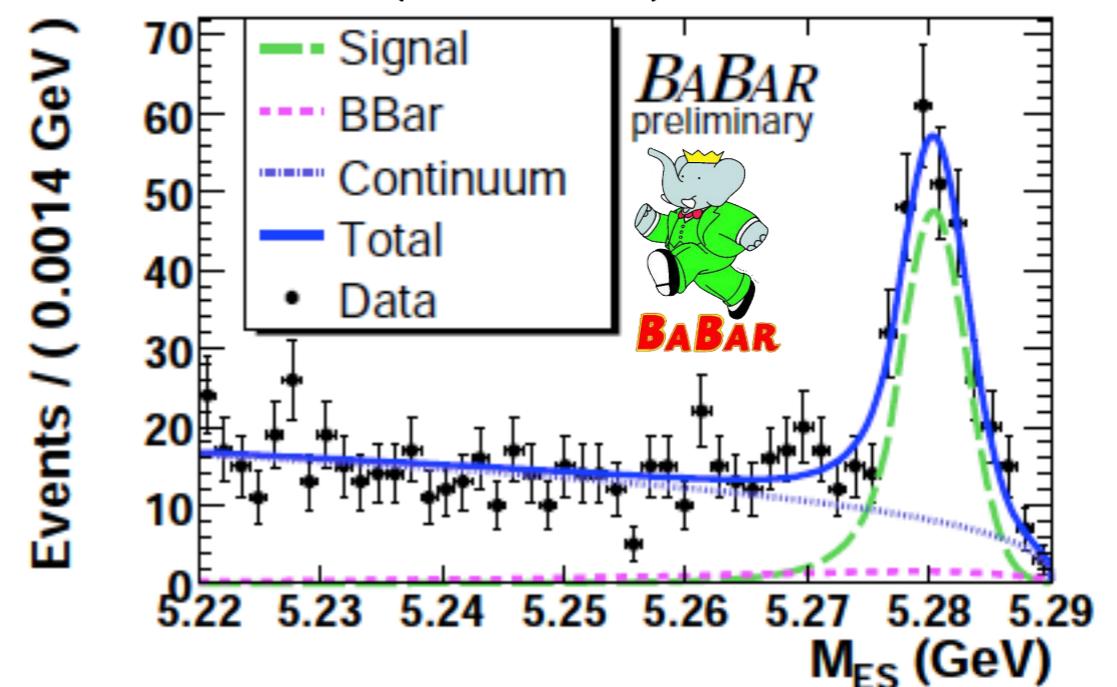


$$K^{*+} (K^+ \pi^0) \gamma$$



New

$$K^{*0} (K_S \pi^0) \gamma$$



Branching ratios for $B \rightarrow K^* \gamma$:



85M $B\bar{B}$

PRD 69, 112001 (2004)



383M $B\bar{B}$

arXiv:0808.1915 (2008)

New

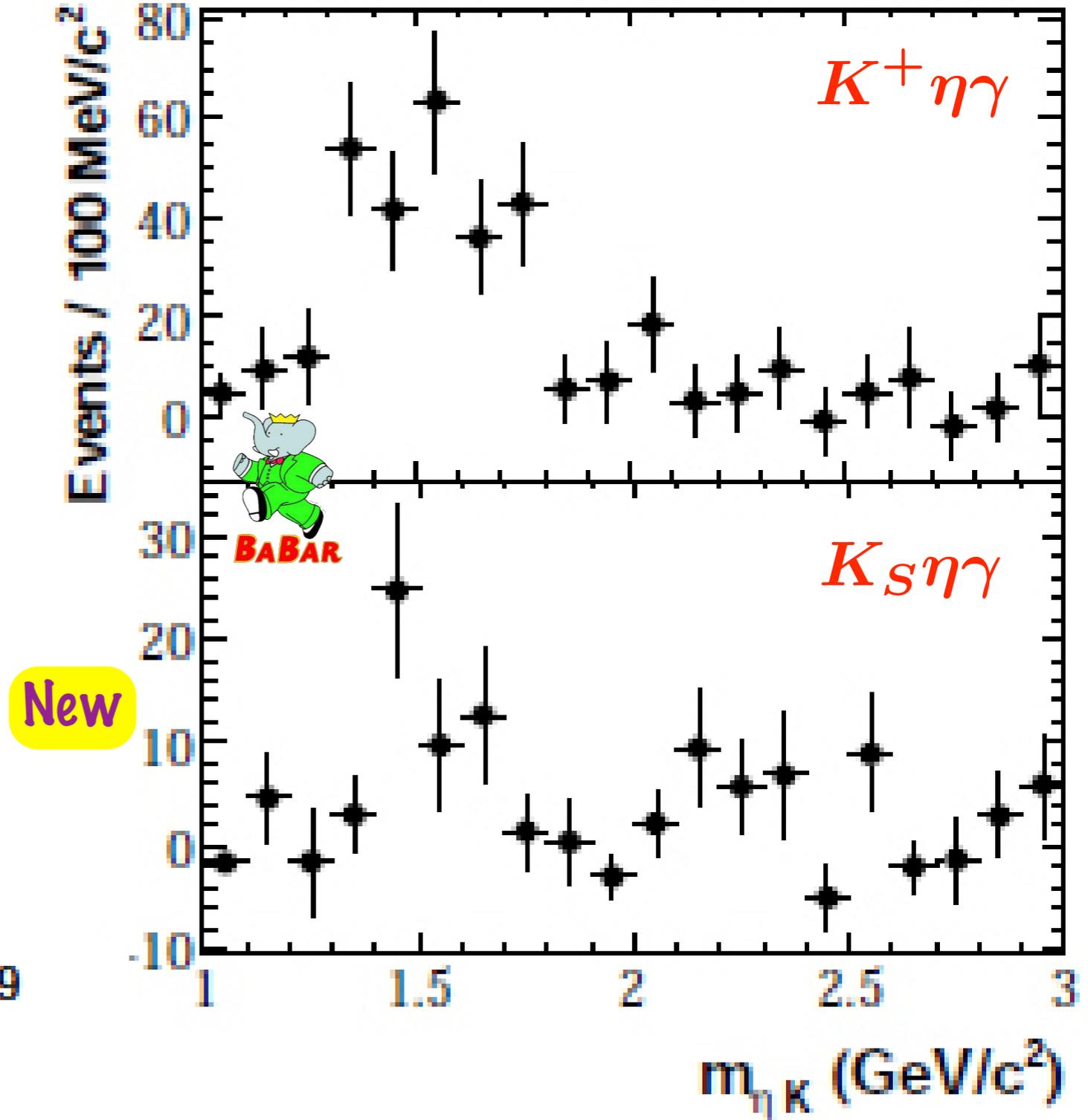
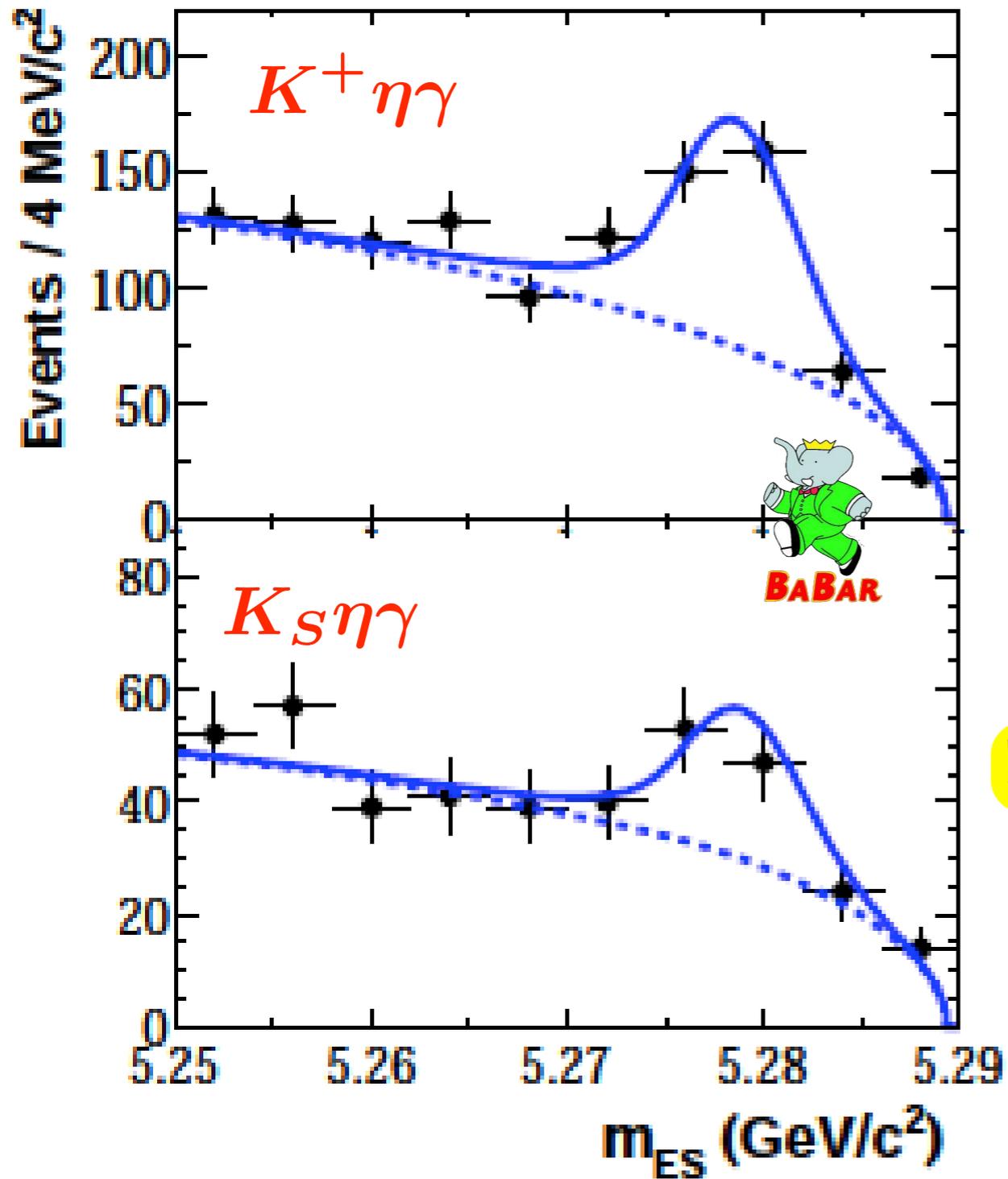
| Mode | $\mathcal{B}(\times 10^{-5})$ | $\mathcal{B}(\times 10^{-5})$ |
|----------------------|--|--|
| $(K^+ \pi^-) \gamma$ | $4.13 \pm 0.22 \pm 0.18$ | $4.55 \pm 0.11 \pm 0.16$ |
| $(K_S \pi^0) \gamma$ | $2.57 \pm 0.69 \pm 0.20$ | $5.01 \pm 0.40 \pm 0.37$ |
| $K^{*0} \gamma$ | $4.01 \pm 0.21 \pm 0.17$ | $4.58 \pm 0.10 \pm 0.16$ |
| | | |
| $(K^+ \pi^0) \gamma$ | $4.19 \pm 0.48 \pm 0.28$ | $5.05 \pm 0.22 \pm 0.27$ |
| $(K_S \pi^+) \gamma$ | $4.31 \pm 0.41 \pm 0.29$ | $4.56 \pm 0.20 \pm 0.17$ |
| $K^{*+} \gamma$ | $4.25 \pm 0.31 \pm 0.24$ | $4.73 \pm 0.15 \pm 0.17$ |

... again, hard to predict these values precisely.

Branching ratios for $B \rightarrow K\eta\gamma$:

465M $B\bar{B}$

arXiv:0805.1317



Branching ratios for $B \rightarrow K\eta\gamma$:



275M $B\bar{B}$

PLB 610, 23 (2005)



465M $B\bar{B}$

arXiv:0805.1317 (2008)

New

| Mode | $\mathcal{B}(\times 10^{-6})$ | $\mathcal{B}(\times 10^{-6})$ |
|-----------------|--|--|
| $K^0\eta\gamma$ | $8.7 \pm 3.1 \pm 1.9$ 2.7 ± 1.6 | $7.1 \pm 2.1 \pm 0.4$ 2.0 ± 0.4 |
| $K^+\eta\gamma$ | $8.4 \pm 1.5 \pm 1.2$ 0.9 | $7.7 \pm 1.0 \pm 0.4$ |
| $K\eta\gamma$ | $8.5 \pm 1.3 \pm 1.2$ 0.9 | $7.6 \pm 0.9 \pm 0.3$ |

Branching ratios for $B \rightarrow K^{(*)} \ell^+ \ell^-$:

